The Kiowa Core, a Continuous Drill Core Through the Denver Basin Bedrock Aquifers at Kiowa, Elbert County, Colorado

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CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	Meter (m)
gallon per minute (gal/min)	0.06309	liter per second (l/sec)
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	Kilometer (km)

Degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 9/5(°C)+32$$

Degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) by using the following equation:

$$°C = 5/9(°F-32)$$

The following abbreviation is also used in this report: gram per cubic centimeter (g/cm^3)

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ABSTRACT

The Kiowa core was obtained as a component of the Denver Basin Project, a cooperative research effort to study the evolution of the Denver Basin, Colorado. The Kiowa core provides a virtually continuous stratigraphic record of the Upper Cretaceous and lower Tertiary strata of the Denver Basin. The upper portion of the core recovered strata conventionally referred to as the Arapahoe and Denver Formations and the Dawson Arkose. A prominent unconformity marked by a mature paleosol breaks these strata into two unconformity-bounded sequences; the lower sequence is termed D1 and the upper sequence, D2. Beneath these units and also penetrated by the core occur the Laramie Formation, Fox Hills Sandstone, and Pierre Shale.

The site for coring was selected in order to obtain fine-grained strata suitable for both palynological and paleomagnetic analyses. The coring effort recovered 93 percent of the 2,256 ft of rock penetrated, resulting in a nearly continuous record of the sedimentary rocks recording the retreat of the Cretaceous Interior Seaway and the subsequent uplift of the Front Range portion of the Rocky Mountains.

Palynological data constrain the Cretaceous-Tertiary boundary to a depth between 878 and 880 ft in the core. The palynological data also serve to bracket the age of the paleosol marking the unconformity between the D1 and D2 sequences to between middle Paleocene and earliest Eocene. The paleomagnetic data are interpreted to represent polarity intervals ranging from polarity subchrons 31r to 28n and polarity subchron 24r.

Hydrologic analyses indicate variable aquifer characteristics across the State-defined bedrock aquifers. Individual aquifer units exhibit generally lower water-yield potential than was identified to the west in a core drilled by the U.S. Geological Survey (USGS) in 1987 at Castle Pines, Colorado. Down-hole temperature measurements indicate a normal geothermal gradient of 30°C/ km. Perturbations of the gradient may represent active fluid flow through the aquifers penetrated by the core.

Petrographic examination of the cored sandstone and mudstone units document both the clay-rich character of the paleosol series marking the boundary between the D1 and D2 sequences, and variation in sandstone composition with depth. The lower sequence (D1) is characterized by litharenites with a significant volcaniclastic component, while the upper sequence (D2) is more arkosic. Extensive lignite beds occur in D1 in the cored interval and these appear as strong reflectors on the seismic line that passes near the core hole. A set of electric logs, core descriptions, and derived data sets accompany this report.

INTRODUCTION

The Denver Basin Project was established by the Denver Museum of Nature and Science (DMNS) (formerly the Denver Museum of Natural History) in 1998 as a multi-disciplinary, multiorganizational effort to study the geology, geohydrology, and paleobiology of the Upper Cretaceous and lower Tertiary sedimentary rocks that comprise the bulk of the bedrock aquifers of the Denver Basin. These rocks are of interest because they contain the depositional record of the retreat of the Cretaceous Interior Seaway and the uplift of the Front Range portion of the Rocky Mountains. These sedimentary rocks comprise the bedrock aquifers supplying groundwater to residents of the Denver Basin, and they also contain the record of the Cretaceous-Tertiary boundary event. As part of the Denver Basin Project, a core-drilling program was conducted in the town of Kiowa, Colorado (fig. 1), with the objective of obtaining a continuous drill core from the land surface to the top of the Pierre Shale. Coring was successful and drilling terminated in the upper Pierre Shale at a depth of 2,256 ft below the Kelly Bushing (KB) elevation of 6,363 ft. In this report all depth measurements dealing with the core are reported as feet below KB. This is conventional in the drilling industry. Selected measurements and analyses are reported in metric units, resulting in mixed units within the following text. A conversion table is provided at the front of the report. The core is stored at the USGS Core Research Center at the Federal Center in Lakewood, Colorado. The core hole currently serves as a water monitoring well in the Denver aquifer. Standing water levels have been measured at 319.4 ft and 322.1 ft below surface in May 1999 and March 2000, respectively.

The project team consisted of the DMNS (coordinating organization); the USGS Water Resources and Geologic Disciplines; the Colorado Department of Natural Resources; Office of the State Engineer; the Colorado Geological Survey; Elbert County; Colorado State University; University of Colorado at Boulder; New Mexico Institute of Mining and Technology; University of Alaska at Fairbanks; and the Scripps Institution of Oceanography. The DMNS acted as the umbrella organization under which the study was conducted. The DMNS also directed and conducted the geologic and paleontologic aspects of the study. The USGS Water Resources Discipline directed geohydrologic aspects of the study in cooperation with Colorado State University. The Layne-Western Division of Layne Geosciences, Inc. conducted the core-drilling operation. Geophysical logging was conducted by the Colog Division of Layne Geosciences, Inc. Temperature logging was conducted by the New Mexico Institute of Mining and Technology. The seismic line was acquired by R. J. Grundy and Associates.

Core samples were analyzed to determine the porosity, permeability, hydraulic conductivity, palynology, paleomagnetism, mineralogy, petrography, and fission track properties of the Denver Basin bedrock aquifers at the study site. Geohydrologic analyses of the core were conducted at the Department of Earth Resources at Colorado State University; palynological analyses of the core were conducted by the DMNS; the paleosol layer was analyzed at the Department of Geological Sciences at the University of Colorado, Boulder; paleomagnetic analyses of the core were conducted by the Geosciences Research Division of Scripps Institution of Oceanography; mineralogy and petrography of the core was analyzed by the DMNS; and fission track properties of the core were determined at the Department of Earth and Environmental Science at the New Mexico Institute of Mining and Technology. Descriptions of these analyses together with the observed data are presented below.

Purpose of the Denver Basin Project

The data presented in this report were collected to help develop an integrated geological and paleobiological framework for the Upper Cretaceous and lower Tertiary sedimentary rocks in the Denver Basin. These sedimentary rocks record the withdrawal of the Cretaceous Interior Seaway and the subsequent birth and evolution of the Front Range segment of the Rocky Mountains. Previous studies (for example, Dane and Pierce, 1936; Brown, 1943; Reichert, 1956; Soister, 1978a; Kirkham and Ladwig, 1979) have developed a general framework for the age and environments of deposition represented by these rocks. Due to vegetation and soil cover in the area, there are no outcrop exposures of the continuous rock record. By obtaining a core through the entire succession, we permit examination of a continuous record of layered sedimentary rocks, obtaining a more detailed record of the depositional and paleobiological features associated with the evolution of the basin. A goal of the Denver Basin Project is to construct a chronostratigraphic and biostratigraphic reference for the Denver Basin based on magnetostratigraphy, lithostratigraphy, and palynostratigraphy of the Kiowa core. This reference section will serve as the basis for developing an integrated paleobiological and geological framework for Upper Cretaceous and lower Tertiary rocks in the Denver Basin. This framework will in turn serve as the basis for testing hypotheses related to the evolution of the Denver Basin and the Cretaceous-Tertiary boundary event. Extensive private and public construction in the 1990's has led to the creation of ephemeral outcrops that have yielded numerous fossils of relatively unconstrained stratigraphic position. The core will help to place these finds into a regional temporal context.

We also seek to obtain data on the hydrologic characteristics of the bedrock aquifers in an area of the Denver Basin where relatively little quantitative data are available. Beyond the present studies, we anticipate that the core from Kiowa will serve as a significant calibration point for future studies of the Denver Basin.

Scope of this Open-File Report

This report is designed to provide a summary of events associated with the coring of a 2,256-foot well in Kiowa, Colorado, and to present basic data collected during 1999 and 2000 from core analyses, aquifer testing, geophysical logging, and seismic profiling of the bedrock aquifers at the study site. It also contains sections provided by researchers who have studied individual aspects of the core samples. The report is a compilation of data obtained before December 2000. In keeping with the Open-File format, this report provides for the release of basic data and is considered preliminary.

Rationale for Coring and the Selection of the Kiowa Drill Site

Analyses of available outcrops and electric logs from the Denver Basin suggest that the history of the basin is recorded in the strata preserved in its central portion (Raynolds, 1997). Outcroppings of these rocks are poor and discontinuous in the basin. A cored well is the only suitable means to obtain a high-resolution continuous record of the strata. A previous drilling effort recovered a relatively coarse-grained, core near the Colorado Front Range at Castle Pines in 1987 (Robson and Banta, 1993). To obtain a record of fine-grained strata, which was anticipated to be more suitable for both palynological and paleomagnetic analyses, our drill site is far from the mountains, in an area where core from the full suite of rock units of interest can be collected with a minimum amount of drilling. The core hole location was also designed to obtain hydrologic information about the bedrock aquifers in an area of the Denver Basin where existing data are sparse. Published reports (for example, Robson and others, 1981a, 1981b) indicate that no deep groundwater data is available for hundreds of square miles surrounding Kiowa.

Acknowledgments

Primary funding for this project was provided by the National Science Foundation, the Colorado Water Conservation Board, and the office of the Colorado State Engineer. Additional support was provided by the U.S. Geological Survey; Colorado Division of Water Resources; Colorado State University; Colorado State University Extension Office in Kiowa, Colorado; Elbert County Water Advisory Board; Elbert County Commissioners; Prima Energy; and RockWare Inc. Preparation of this report could not have been accomplished without the editorial efforts of Chuck Pillmore, Steve Roberts, and Kathy Varnes. We also acknowledge the help of Sara Plumlee and Vanessa Graves, and the core handling and logging assistance of Paul Harnick, Regan Dunn, Rich Barclay, and Shannon Romo. Drilling and logging was handled with skill and good will by Layne-Western representatives Brian Dellett, Mark Scharenbroich, Jerry Ahartz, Pat Collins, Shane Crum, Tim Lucky, Steve Hawkins, Greg Baur, and Joe Nelson. The Elbert County Commissioners together with Gary Brooks, Mayor of Kiowa, and the staff of the Elbert County Extension Office, particularly Kipp Nye, Becky Taylor, Connie Hoesel, and Ryan Miller, were extremely helpful. The volunteered time and efforts of Shirley Alvarez, Mary Bonnell, Ray Bridge, Thomas Cleary, Cheryl DeGraff, Pat Ervin, Danny Feiken, Glenn Graham, Bill Haynes, Bill Keebler, Bill Kinneer, Adrian Kropp, Jerry and Paula Koch, Gene Lindsey, Dena Meade-Hunter, Tom Michalski, Jim Reed, Michele Reynolds, Bill Sanford, Matt Sares, Jeff Stephenson, Susan Van Gundy, George Van Slyke, Amber Taylor, Lou Taylor, Steve Wallace, and Sue Ware are gratefully acknowledged. The importance of the core for hydrologic studies was recognized by Stan Robson, and his enthusiastic support during the formulation of the project as well as during the drilling and curation phases is acknowledged with special gratitude.

DESCRIPTION OF THE DRILL SITE

Location and Facilities

The core hole was drilled in the northwest quarter of the southeast quarter of section 17, T. 8 S., R. 63 W., on the Elbert County Fairgrounds in the town of Kiowa, Colorado, at 39° 21' 08.7" N, 104° 27' 59.1" W (fig. 1). The site is at an altitude of 6,363 ft on the eastern flank of the Kiowa Creek drainage, and is near the geographic center of the accumulation of sediments that comprise the principal bedrock aquifers in the Denver Basin (fig. 2). The core site on the Elbert County Fairgrounds was selected in cooperation with Elbert County officials to optimize site logistics and minimize site disturbance. The site is about 100 meters NNW of the Agriculture Building on the Fairgrounds. The County made the Agriculture Building available for our on-site studies. A work area and display area were set up and manned by DMNS personnel from March 2, 1999 to April 19, 1999.

Geology and Geohydrology

The Denver Basin is a large structural depression that extends from the Front Range of Colorado into western Nebraska, Kansas, and eastern Wyoming (Robson, 1989) and reaches a maximum thickness of about 15,000 ft southwest of the drill site near the Elbert-El Paso County line (Robson and Banta, 1987, pl. 1). Beds dip steeply into the basin along its western margin and dip gently into the basin along its eastern, northern, and southern margins. The rock units and bedrock aquifers described in this report are Upper Cretaceous and lower Tertiary sedimentary layers that occupy the part of the Denver Basin above the Pierre Shale (fig. 3). Traditional geologic terminology in the basin has been modified in this report because the compositional criteria used to differentiate the Denver Formation (generally rich in andesitic material) and Dawson Arkose (generally rich in feldspathic material) are difficult to use consistently over wide areas of the basin (Soister, 1978b; Crifasi, 1992; Raynolds, 1997). With the goal of presenting information from a genetic standpoint, two unconformity-bounded sequences of strata were defined by Raynolds (1997); these sequences are separated by a mature paleosol series representing a regional unconformity. The lower sequence is termed D1 (D standing for Denver) and is bounded at its base by the unconformity at the base of the conglomeratic Arapahoe Formation as defined southwest of Denver by Eldridge (1896). These conglomerate beds lie unconformably on the Laramie Formation and contain the first coarse crystalline clastics derived from the uplifted Front Range. The top of the D1 sequence is delimited by a strongly weathered unconformity marked by a regional paleosol first identified by Soister and Tschudy (1978). The D2 sequence is bounded at its base by the top of the regional paleosol. The D2 sequence is bounded at its top by an unconformity separating D2 strata from the overlying Castle Rock Conglomerate and Wall Mountain Tuff, which is also known as the "Castle Rock Rhyolite" (Trimble and Machette, 1979).

Thus, the rock units discussed in this report are (in ascending order from oldest to youngest): the Pierre Shale, the Fox Hills Sandstone, the Laramie Formation, and the overlying D1 and D2 sequences. The D1 sequence is comprised of the Arapahoe Formation and portions of both the Denver Formation and the Dawson Arkose. The D2 sequence is comprised of most but not all of the Dawson Arkose.

Above the Pierre Shale, these same strata are divided into four hydrostratigraphic units, which are, in ascending order, the Laramie-Fox Hills, Arapahoe, Denver, and Dawson aquifers (fig. 3). The Pierre Shale is considered to be the basal confining unit of the bedrock aquifers in the Denver Basin.

Preliminary evidence of westward thickening and increased sandstone abundance in the Laramie Formation suggests it may have accumulated during a transitional time as the Denver Basin was starting to subside, yet before there was significant relief established on the Front Range. The Laramie Formation contains coal beds that have been extensively mined around the periphery of the Denver Basin. Core samples from these coal beds were analyzed for isotopic characteristics by R.A. Zielinski of the USGS and results are shown in table 1.

Above the Laramie Formation, the D1 and D2 sequences accumulated during times when there was developing relief in the Front Range area. Because they accumulated contemporaneously with the orogenic activity, the sequences are termed synorogenic.

Figure 2 shows the general outcrop pattern of the aquifers. The bedrock geology of the Denver Basin is shown in figure 4, and the thickness of the synorogenic strata is shown in figure 5. Figure 6 shows a generalized cross-section of the principal aquifers in the Denver Basin and figure 7 shows a geological cross section across the upper portion of the Denver Basin.

Sequence of Events During Drilling

Surface casing was set on February 24, 1999, and the first 70 ft were drilled using an auger tool. Core drilling commenced on the morning of March 1, 1999. We acquired 2.5-inch-diameter core in 5-foot segments using a split tube, wire line system. Drillers worked in 12-hour shifts and DMNS staff worked in 8-hour shifts, as drilling proceeded around the clock.

Drilling continued for 11 days at a rate of about 132 feet per day until a depth of approximately 1,460 ft followed by a pause of a few days for rig repair. Drilling started again on March 14, 1999, to a depth of 1,880 ft at a rate of approximately 70 feet per day.

At 1,880 ft, in the upper portion of the Fox Hills Sandstone, both rig and hole problems were encountered that persisted for 11 days. Steel casing was installed to a depth of 1,797 ft to stabilize the hole and drilling started again on April 1, 1999. A portion of the Laramie Formation was re-drilled as coring proceeded to a total depth of 2,256 ft at a rate of approximately 75 feet per day. Total depth was reached on April 6, 1999.

Geophysical logs were obtained in a series of three runs. The logging suite consisted of caliper, gamma ray, spontaneous potential, resistivity, compensated density and full waveform sonic logs. Because of difficulties in getting the lightweight resistivity tool down the hole, a 452-ft-segment of hole between 1,412 and 1,864 ft has no resistivity log coverage.

The well was developed for approximately six hours using a bailer immediately following completion of the well. Efforts to obtain uncontaminated water samples from deep aquifers were not successful as the pH of all samples indicated extensive contamination by drilling fluids. Later, a series of temperature profiles were measured in the fluid-filled well.

The core hole was completed as a monitoring well with 2-inch-diameter steel casing set in the Denver aquifer to a total depth of 734 ft on April 20, 1999. Figure 8 shows how the monitoring well is constructed. Screen intervals in the well were placed adjacent to prominent sand layers in the Denver aquifer. Blank intervals are adjacent to layers composed primarily of mudstone.

CORE LOG AND DESCRIPTION

Graphic Core Log

The core was photographed and described as it was collected in Kiowa. Grain size, color, and stratigraphic features were recorded on site. Later the core descriptions were reviewed and edited at the USGS Core Research Center to ensure that there was a uniform style of description and observation. The nomenclature of the cored units is shown in figure 3 and a graphic core log is shown as figure 9. The cored units are described in table 2.

Stratigraphy and Lithology

Beneath 58 ft of unconsolidated alluvium deposited by Kiowa Creek, the core enters the upper sequence of synorogenic strata termed D2. The D2 sequence is comprised of 282 ft of alternating sandstone and mudstone layers. The sandstone layers typically have abrupt bases and gradational tops and the mudstone units show weak soil development. The top of the paleosol series that separates the D2 sequence from the underlying D1 sequence occurs at a depth of 340 ft. The paleosol series is 14 ft thick and is described in detail in a subsequent section of this report.

Beneath the paleosol, D1 strata occur to a depth of 1,648 ft. These strata are characterized by alternating sandstone and mudstone layers with a significant proportion of lignite between 430 and 1,130 ft. At the base of D1, a one-foot-thick gravelly sandstone bed represents the basal conglomerate of the Arapahoe Formation. The sandstone beds in D1 typically have abrupt bases and gradational tops and the intervening mudstone units show weak soil development.

Beneath the D1 sequence the Laramie Formation occurs to a depth of 1,851 ft. The Laramie Formation is generally shaly with few significant sandstone beds and has a series of coal beds near its base.

Beneath the Laramie Formation, the Fox Hills Sandstone occurs from 1,851 ft down to a depth of about 2,120 ft. The Fox Hills Sandstone is composed of massive quartz-rich sandstone beds that become increasingly shaly downwards into the Pierre Shale. The transition into the Pierre Shale is picked at approximately 2,120 ft and coring was completed in the Pierre Shale at a total depth of 2,256 ft. The Pierre Shale is a dark, well-bedded shale with invertebrate fossils. The bedding fabric is commonly disrupted by bioturbation.

As mentioned, the sandstone beds cored in D1 and D2 have sharp erosive bases and transitional tops and the intervening mudstone beds often show evidence of soil formation. These sandstone beds are interpreted to be of fluvial origin. The sandstone mineralogy suggests that the D1 rivers drained a mixed terrain of granitic and volcanic rocks whereas the D2 sandstone beds indicate a granitic source area. The Laramie Formation mudstone beds also show signs of soil formation and, together with the coal beds near the base, suggest floodplain and mire environments. The massive quartz-rich sandstone beds of the Fox Hills Sandstone represent the near-shore and beach facies deposited as the Cretaceous Interior Seaway retreated from the Denver Basin area. The underlying fossiliferous Pierre Shale beds are interpreted to have been deposited in a marine environment.

ANALYSES OF CORE SAMPLES

Geohydrology

Hydrologic studies were conducted to determine the nature and quality of the bedrock aquifers in the vicinity of the Kiowa core hole. Previously, most such analyses in the Denver Basin had been conducted from shallow wells or outcrops.

Samples from the Kiowa core consist of whole core segments typically 20-30 cm long. Sample intervals were chosen by the USGS based on the lithology of the core in each aquifer. Samples were coated in jewelry wax to keep the core moist and consolidated. The samples were analyzed at the Colorado State University Hydrogeology Lab for hydraulic conductivity, porosity, specific yield, and grain-size. The results are summarized below and appear in more detail in the Master's thesis of Laura Lapey (2001).

a. Hydraulic conductivity

Laboratory determination of vertical hydraulic conductivity was conducted in accordance to American Society for Testing and Materials (ASTM) Standard D 2434-68. A constant head permeameter was built for the coarse-grained samples (fig. 10). The waxed core samples were cut into 7-12 cm sections using a water-lubricated rock saw. Three-inch PVC caps fitted with gravel and screen were attached with wax to each end of the sample. De-aired tap water is forced into the bottom of the permeameter under a natural gradient and the rate at which the water exits through the sample is measured. Experiments were conducted approximately 15 hours after flow started. At least three runs were used to determine the hydraulic conductivity of each sample.

De-aired tap water was used for the hydraulic conductivity experiments to ensure that no air filled the pore spaces. The water was subjected to a vacuum of 25 mm Hg for two hours until the air bubbles ceased. A large carboy fitted as a Mariotte bottle was used for constant head control.

The samples were also de-aired by placing them under a 25mm Hg vacuum for 20 minutes before water was allowed to enter the sample (ASTM D 2434-68). The sample remained under vacuum until flow was achieved.

Hydraulic conductivity (K) is calculated using Darcy's Law:

$$\mathbf{K=Q\Delta L/A\Delta h}$$

Where: Q = water discharge rate; ΔL = sample length; A = sample area; Δh = change in head

Fine-grained samples were tested using a falling head permeameter, where the amount of water entering the sample is measured instead of the rate at which water exits the sample (fig. 11). The PVC caps are fitted with a porous stone and screen to prevent silt and clay from washing out of the sample. The same procedures are followed as described above.

The hydraulic conductivity for this method is calculated by:

$$\mathbf{K= aL/At \ln (h_0/h_1)}$$

Where: a = area of the manometer; L = sample length; A = sample area; t = time; h_0 = initial head; h_1 = final head

Preferential flow of water between the sample and the wax walls was a concern. After each test, food coloring was injected into the inflow tube and allowed to circulate through the sample. If the dye stained the outer edges of the core, the sample was re-waxed and tested again.

Several samples were tested using an air permeameter, designed by Arthur Corey at the Colorado State University Porous Media Lab. The air permeameter measures the permeability of the sample to air, which must then be converted to water permeability or hydraulic conductivity. The air permeameter is used for samples that are too fine-grained for the falling head permeameter.

A one-inch diameter plug is drilled from the core sample using a drill press and dried in an oven at 105° C for 24 hours. The plugs are then placed in the chamber to be tested in the air permeameter. A diagram of the air permeameter is shown in figure 12. Air is forced through the sample, and the rate of outflow is measured using a soap film flowmeter, which measures the flux directly. The gradient is fixed at the air pressure manometer to the approximate length of the sample before the test begins and the change is recorded during each test run.

The air permeability (k) is calculated by:

$$\mathbf{k = \{V/A*t\} * \{\mu*\Delta L/\Delta P*g\}}$$

Where: V = volume of flow meter (cc); g = gravity; A = sample area; ΔP = change in pressure; t = time (sec); ΔL = change in length; μ = air viscosity

Air permeability (k) is then converted to water permeability or hydraulic conductivity (K). This is accomplished by:

$$\mathbf{K = (k^*\rho_w^*g)/\mu_w}$$

Where: K = Hydraulic conductivity; ρ_w = density of water; k = intrinsic permeability (air); μ_w = viscosity of water; g = gravity

To prevent air from flowing between the sample and the chamber walls, the air permeameter was designed with a rubber sleeve, which was held against the outer circumference of the sample with a pneumatic pressure of between 5-20 psi (Brooks and Corey, 1964).

The hydraulic conductivity data results of the Kiowa core samples can be found in table 3.

b. Specific yield and porosity

Laboratory determination of specific yield is conducted in accordance to ASTM Standard D 2335-68 and with the use of the same laboratory methods used by David McWhorter on the Castle Pines core project. The equipment consists of standard pressure plate apparatus manufactured by the Soil Moisture Equipment Company, Inc. Ceramic pressure plates with 1, 3, 5, and 15-bar entry pressures are utilized, and pressure is supplied using a Soil Moisture air compressor and/or cylinders of compressed nitrogen.

Samples are approximately 6 cm in diameter and were sectioned into duplicate 2 to 3 cm increments. The jeweler's wax coating remains around the sample to maintain its shape. The waxed core cylinder is then wrapped in a brown paper towel, which is secured at the top with a rubber band. The purpose of the towel is to keep the sample contained so an accurate weight is obtained. Duplicate samples are labeled "a" and "b" and are typically sectioned adjacently in the core sample.

Before samples are placed in the pressure chamber, they must be completely saturated. This is accomplished by natural saturation in de-aired water for twenty-four hours followed by one hour in an evacuation chamber at a vacuum of 20 mm Hg. The saturated samples were wiped of excess water, weighed, and placed on a previously saturated porous plate in the pressure chamber. The saturated weight will be used to calculate porosity.

To maintain good hydraulic connectivity between the sample and the porous plate, a lead weight was placed on top of each sample. This ensures that the sample makes good contact with the plate. The pressure chamber must remain humid to prevent the samples from drying out. To accomplish this, wet paper towels are placed on top of the samples.

The procedure consists of determining the weight of the samples at each desired capillary pressure (suction), which for this experiment includes 0.5, 1, 3, 5, and 13.5 bars. An equilibration weight is necessary in order to proceed to the next desired pressure. Equilibration periods of 48 hours are used for pressures of one bar or less and at least 72 hours are required for 3-13.5 bars. After the samples are weighed at 13.5 bars, they are oven-dried at 45° C for 96 hours. The standard 105-degree drying temperature was not used due to the low melting temperature of the wax (McWhorter and Garcia, 1990).

Each sample is contained in wax and wrapped in a paper towel. The water contained on the wax and towel must be subtracted from each of the sample weights. A test sample, containing just wax and towel, is run with each round of samples. The weight (W) of the test sample at each pressure level is subtracted from the dry weight of the test sample. This value constitutes the rough weight of water retained by each sample held by the wax and towel alone.

$$W_{test} = W_{test\ at\ pressure} - W_{test\ dry}$$

The volumetric water content of the samples at 13.5 bars is considered to be the specific retention (McWhorter and Garcia, 1990). It is calculated by determining the volume of pore water and dividing by the bulk volume of the sample.

The volume of pore water retained by the sample at 13.5 bars is the sample weight minus the gross dry weight minus the test weight divided by the mass density of water, which is assumed to be 1 g/cm^3 in all cases.

$$\theta_{vol} = [W_{sample\ 13.5\ bars} - W_{sample\ dry} - W_{test}] / \rho_{water}$$

Porosity is calculated in a similar manner by taking the saturated sample weight minus the dry weight divided by the mass density of water, and dividing that by the bulk volume of the sample.

$$\phi = [(W_{saturated\ sample} - W_{dry\ sample}) / \rho_{water}] / V_{sample}$$

The specific yield is then obtained by taking the calculated porosity value minus the calculated specific retention value.

$$S_y = \phi - S_r$$

The volumetric water content at each pressure level is measured. Duplicate samples should have similar retention curves, and if they do not, there is a problem. One common problem is not achieving good hydraulic connection between the porous plate and the sample. If this occurs, the retention curve on the graph is a straight line.

The results for the porosity and specific yield data for the Kiowa core can be found in table 4.

c. Grain-size analysis

Each of the samples was gently crushed with a mortar and pestle, dried in an oven at 105° C, and mechanically sieved according to ASTM Standard D 422. The sieve sizes in millimeters used for this experiment range from 0.0526 to 16. The finer-grained, more consolidated samples require more crushing than the medium-grained sandy samples.

Between 200-300 grams of each sample were sieved. The particles remaining on each sieve were weighed and recorded. The percent of the total sample volume was then calculated by:

(weight determined on sieve / total sample weight) x 100

This is then used to calculate the percent finer by summing all percent totals finer than a particular sieve size. For example, if zero grams of sample remained on the 16mm sieve, the percent total would be zero and the percent finer would be 100 percent.

The percent finer was graphed against sieve size in millimeters. From the graph, D30, D50, and D90 can be determined for each sample. For example, D30 represents the grain-size at which 30 percent of the sample is finer by weight.

The grain size analysis data is presented in table 5.

Paleosol Series in the Kiowa Core

Description

The Kiowa core contains the mature paleosol series recognized by Soister and Tschudy (1978), which separates the synorogenic sediments in the Denver Basin into two unconformity-bounded sequences termed D1 and D2. The paleosol series in the core is 14 ft thick and occurs at a depth of 340 to 354 ft. Nine stratigraphic units are identified based on grain size, mineralogy, and pedogenic features (fig. 13). The nine units collectively are 90 percent mudstone and 10 percent sandstone with a significant portion of core lost.

Pedogenic features characterizing the paleosol sequence are slickensides, mottles, root traces and casts, and ped-like features. Pedogenic structures were determined by hand sample analysis under a binocular microscope. Slickensides are prevalent in three of the nine units and are often intersecting. Mottles are present in two of the nine units and are red, dark gray, and moderate yellowish brown in color. Mottle sizes varied from 3-10 cm in diameter. Root traces are present in one of the nine units in the core and are associated with red and yellow mottles. The traces are vertical and horizontal in nature and are clay-filled. In general root traces are small with diameters of 5 mm or less. Polypedon structures in the paleosol are often bounded by slickensides and provide planes of weakness causing samples to break into ped-like fragments.

Color variations in the paleosol sequence are determined using a Munsell color chart and span a range from light gray N7 to medium bluish gray 5B 5/1 to a dark reddish brown 10R 3/4. The most common color is gray. One unit is brightly colored with reds and yellows.

The micromorphology of the paleosol sequence was analyzed using thin sections made from each unit. Distinctive features include clay skins, disrupted fabrics, alluvial clay, patchy iron-oxide impregnations, and sphaerosiderite crystals, a morphologically distinctive form of siderite. There is also a lack of organic material within the paleosol interval. Analytical results are summarized below; further interpretations are developed in the University of Colorado Master's thesis by Farnham (2001).

X-ray Diffraction and X-ray Fluorescence

The mineralogy of the paleosol sequence was determined using a Scintag Powder X-ray Diffraction (XRD) machine at the University of Colorado at Boulder. The XRD machine uses x-rays generated by a copper filament to bombard samples and determine the spacing of the crystal lattices of atoms. Each mineral has a unique set of lattice spacings that cause the x-rays to reflect at specific angles. The whole rock mineralogy is determined by grinding a sample of the unit to be tested into a powder. The powder is then placed into a sample holder. It is then placed onto a target in the XRD machine and bombarded by x-rays through a range of angles (2-70 degrees). The x-ray reflections are measured and matched with known patterns for minerals.

In order to determine the clay mineralogy the clay fraction must first be separated out. This is done by placing a sample of rock in a test tube, mixing it with de-ionized water and sodium phosphate (a deflocculating agent), agitating the sample, then letting the heavier fractions settle out. The topmost fluid is pipetted out and dripped onto a ceramic tile to dry. The clay fraction is left on the tile as a film. The tile is run through the XRD after air-drying.

The weight percent of major oxides is determined using x-ray fluorescence (XRF). XRF analysis was performed at the geology lab at the University of Colorado at Boulder. The ratios of major oxides are used to determine the change in clay content, degree of weathering, and translocation of iron or other selected minerals through a paleosol profile.

The whole rock mineralogy of the paleosol sequence is dominated by quartz and the 1:1 dioctahedral clay mineral kaolinite [$Si_4Al_4O_{10}(OH)_8$] and the 2:1 dioctahedral layered silicate smectite [$Al_2Si_4O_{10}(OH)_2$]. Other significant components are the iron carbonate siderite [$FeCO_3$] found in nodular and single crystal form, and minor amounts of the layered silicate illite [$KAl_4(Si_7AlO_{20})(OH)_4$]. The clay mineralogy is primarily kaolinite and smectite although the uppermost units (5-9) contain less than 2 percent smectite and minor amounts of illite. Results of the x-ray diffraction analysis are presented in figure 14. Results of the clay sized x-ray diffraction analysis are presented in figure 15. Results of the XRF whole-rock analyses are presented in figure 16.

Palynology

Fossil pollen and spores (palynomorphs) are often preserved in fine-grained, organic-rich sedimentary rocks because of the durability of these fossils. Analysis of palynological assemblages recovered from a sequence of rocks can provide insight into floral changes through time. These changes can be used to determine the age of the rocks and the nature of the vegetation present at the time of deposition.

Methods

Samples of mudstone, carbonaceous shale, and lignite were collected from the core for palynological analyses. Samples were generally small (about 15-25 gm). They were shipped to Global Geolab Ltd. in Medicine Hat, Alberta, where they were processed using standard palynological procedures. Slides were shipped back to Denver and scanned for biostratigraphically useful taxa.

Results

Samples were analyzed for the purposes of locating the Cretaceous-Tertiary (K-T) boundary, constraining the age of the prominent paleosol that marks the D1-D2 boundary, and developing a reference pollen biostratigraphy section for the Denver Basin.

In general, palynological recovery from the Kiowa core is good. Most samples submitted for processing yield well-preserved palynomorph assemblages. This is primarily due to the fresh, un-weathered character of the material recovered from the core. Rock samples from natural exposures are often oxidized and palynomorph recovery is in general far better from core samples.

Little evidence of mixing of older fossils into younger rocks was observed in samples below 426 ft in the Kiowa core. Samples above 426 ft contain some reworked fossils, including marine dinoflagellates reworked from rocks of Cretaceous age. However, the relative abundance of reworked specimens is lower than is found in samples from the western part of the Denver Basin. The palynostratigraphic zonation above the K-T boundary is based primarily on the first appearances of members of the *Momipites-Caryapollenites* lineage; first appearances are not affected by reworking.

Table 6 contains a list of all samples collected from the Kiowa core for palynological analysis. The table also summarizes palynostratigraphic presence/absence data. Table 7 lists age-diagnostic fossils that have been observed to date in the Kiowa core.

a. Cretaceous-Tertiary boundary

The palynological K-T boundary was located in the Kiowa core based on the extinction of Cretaceous pollen species, including species of the genera *Proteacidites* and *Aquilapollenites,* which are genera that characterize the *Wodehouseia spinata* Assemblage Zone (Nichols and others, 1982). In sequences where reworking is not a problem, fossils of these genera occur in uppermost Cretaceous rocks but disappear precisely at the K-T boundary.

Based on palynological assemblages, the K-T boundary occurs in the Kiowa core below 878 ft 4.5 in and above 880 ft 2 in. Because a small interval of core was lost at this depth, a K-T boundary claystone was not located and more precise positioning of the boundary in the Kiowa core is not possible. The estimated position of the boundary in the core will be used to aid in locating natural exposures of the boundary interval along the eastern margin of the Denver Basin.

One aspect of palynological assemblages across the K-T boundary is the presence of a fern-spore abundance anomaly ("fern spike"). In many K-T boundary sections in the Western Interior, assemblages immediately above the boundary contain very high percentages of fern spores, sometimes approaching 100 percent of a single species. R.H. Tschudy first reported and later fully described this anomalous abundance of fern spores in the Raton Basin of southern Colorado and New Mexico (Orth and others, 1981; Tschudy and others, 1984). Since his initial observations, this anomaly has been reported from many additional localities to the north and south of the Denver Basin. Tschudy interpreted the high abundance to represent recolonization of a devastated landscape following the K-T boundary event. The sample just below the missing interval of the K-T boundary in the Kiowa core contains about 50 percent fern spores and the sample just above this interval contains about 75 percent fern spores. Although these data are inadequate to make a definitive interpretation, they suggest the presence of a fern-spore abundance anomaly in the Denver Basin.

b. Age of paleosol

The paleosol series that demarcates the D1-D2 contact in the Denver Basin was recovered in the Kiowa core. Palynological samples were analyzed from the interval containing the paleosol in an attempt to constrain the age of rocks immediately above and below the paleosol.

The stratigraphically highest sample below the base of the paleosol that yielded a good palynological assemblage comes from a depth of 411 ft (71 ft below the top of the paleosol). This sample contains three species of the fossil pollen genus *Momipites*. Two of these species (*M. leffingwellii* and *M. inaequalis*) suggest that the assemblage is from Zone P1 of Nichols and Ott (1978). However, the third species (*M. dilatus*) does not appear until Zone P3 in the Raton Basin (Fleming, 1990). One other specimen in the assemblage may be referable to *M. wyomingensis*, but it is too poorly preserved for positive identification. Based on this evidence, the assemblage is tentatively assigned to Zone P2 of Nichols and Ott, but could be as young as Zone P3 of Nichols and Ott (middle Paleocene).

The stratigraphically lowest samples above the paleosol that yielded good assemblages come from depths of 332 ft and 327 ft (8 and 13 ft above the top of the paleosol, respectively). Both of these assemblages contained several species in the *Momipites-Caryapollenites* lineage, including *Momipites ventifluminis*, *Caryapollenites veripites* and *Caryapollenites inelegans*. In addition, both samples contain rare specimens of *Platycarya platycaryoides*.

In the Bighorn Basin of Wyoming, the earliest occurrence of *Platycarya platycaryoides* is found near the base of Wasatchian strata in rocks currently determined to be earliest Eocene in age (Wing, 1998). Abundant specimens of *Platycarya platycaryoides* are found about 500 meters higher in the Bighorn Basin, still in strata of early Eocene age (Wing, 1998). Based on a comparison with the Bighorn Basin, the presence of rare specimens of *Platycarya platycaryoides* in the Kiowa core samples indicates an earliest Eocene age for the strata immediately above the paleosol.

The paleosol is thus bracketed between rocks of middle Paleocene and earliest Eocene age. This interpretation supports the hypothesis that the paleosol represents a major unconformity. Unfortunately, it is very unlikely that palynomorphs can be recovered from the paleosol itself due to its oxidized nature.

c. Biostratigraphic zonation of the Kiowa core

Based on palynological assemblages, the Kiowa core can be divided into three broad zones. The lowermost zone is Cretaceous in age and extends from about 880 ft to the bottom of the core. The upper part of this zone is Maastrichtian in age (latest Cretaceous, based on presence of fossil pollen species of the *Wodehouseia spinata* Assemblage Zone) but the precise age of the lowermost part of the core has not been determined based on palynology. The middle zone of the core is early to middle Paleocene in age from 878 ft to about 352 ft (base of the paleosol). Above the paleosol, the upper zone of the core is early Eocene in age. This suggests that some of the middle part and the upper part of the Paleocene are missing due to an unconformity, which is marked by the paleosol. The age of the uppermost parts of the core cannot be determined due to poor recovery of palynomorphs, but it is presumably Eocene or younger.

d. Paleoecology

In addition to biostratigraphic interpretations, palynological assemblages provide some insight into the vegetation that was present in the Denver Basin during the Late Cretaceous and early Tertiary. In combination with fossil leaf data gathered elsewhere in the basin, this information can be used to reconstruct the vegetation of the area during the Late Cretaceous and early Tertiary. Preliminary observations from the Kiowa core samples allow general interpretations of the vegetation.

Paleocene palynological assemblages below the paleosol contain numerous species indicative of wet habitats, such as *Azolla* (a water fern), other ferns, *Sphagnum* (sphagnum moss), and *Isoetes* (quillwort). Palynological data support the interpretation of high rainfall that is indicated by leaf assemblages (Ellis and Johnson, 1999). The Eocene assemblages from just above the paleosol are markedly different. They contrast with the Paleocene assemblages in that they contain fewer fern spores, more angiosperm pollen, and higher percentages of pollen referable to a group of gymnosperms, all of which produce similar pollen—the Taxodiaceae, Cupressaceae, and Taxaceae.

The Denver Basin appears to have been located on a paleobiogeographic boundary between the northern and southern parts of the Western Interior. During the early Tertiary, the northern part of the Western Interior included a significant abundance of taxodiaceous elements (e.g., bald cypress). These trees were rare to absent in the southern part of the Western Interior. Samples from the Kiowa core suggest that taxodiaceous trees were present in greater abundance than in the Raton Basin but in lesser abundance than in basins to the north such as the Powder River Basin. In addition, it appears that taxodiaceous trees increased in abundance from Paleocene to Eocene time in the Denver Basin.

Paleomagnetism

Methods

The Kiowa core was extensively sampled for a paleomagnetic analysis. Oriented samples for analysis were collected from each 5-ft core storage tube that contained suitable undamaged and well-oriented rock. This resulted in a complete suite of 327 samples collected from the 399 core tubes of the primary hole, and an additional 51 samples from the 97 core tubes of the secondary hole. Not all these samples are to be used for paleomagnetic analysis, but the full suite of samples collected provides a reference collection of archived samples to meet the needs of present and future analysis.

The paleomagnetic subsamples were prepared from a 2- to 3-inch slice, or full round, cut from the original core. The full round was cut with a diamond saw into four subsamples that were then dry-sanded into cubes, nominally 1-inch square, suitable for measurement in the cryogenic magnetometer. The samples were collected this way because the core sediments were generally too fractured or poorly indurated for the subsamples to be taken by drilling small diameter cores out of the full round. All the subsamples were cut from the full round aligned to an arbitrary witness mark. The core itself is unoriented, and the actual field declination is not known, but with the witness mark the four subsamples from each level could be compared for within-site consistency. The subsamples were labeled "a" through "d", and are referred to as such below, and in Table 8.

All demagnetization and measurement was carried out at the Scripps Institution of Oceanography in a magnetically shielded room, with an ambient field of 200nT. The magnetic measurements were made on a CTF three-axis cryogenic magnetometer. Thermal demagnetization was carried out in air in two high-capacity custom-built ovens modeled after a type developed at the Lamont-Doherty Geological Laboratory. The susceptibility of the samples was measured using a Bartington MS2 susceptibility meter. Progressive demagnetization by both thermal and alternating-field (AF) methods was carried out in steps until the magnetization intensity fell below noise level, or below approximately 8% of the natural remnant magnetization (NRM), or until the measured directions became erratic, or when the low-field bulk magnetic susceptibility increased more than one order of magnitude, indicating alteration of magnetic minerals.

Since there are no published reports of paleomagnetic analyses from the synorogenic strata of the Denver basin, the paleomagnetic analysis was carried out on a series of pilot samples using different methods of stepwise demagnetization and data analysis.

a. Stepwise thermal demagnetization

The first suite of pilot samples was taken at a 20- to 50-ft spacing from 68 stratigraphic levels that ranged from the top to the bottom of the core. Three to four subsamples from each level were measured using a stepwise thermal demagnetization regime of 11 steps (NRM, 125°, 150°, 175°, 200°, 225°, 250°, 250°, 275°, 300°, 325°, 350° C). In no case was there more than a small fraction of the natural remanent magnetization (NRM) remaining after 350°C and in many cases the data became scattered after treatment to about 250 to 300°C. Susceptibility measurements indicate that the scatter probably results from alteration of magnetic mineralogy during thermal demagnetization. The data from the 206 samples processed in this manner were not satisfactory as few samples achieved a consistent or stable direction. The exact reason for the failure of this thermal demagnetization process is not fully understood at present, but will be studied further in the future.

b. Combined thermal and stepwise alternating-field demagnetization

A second suite from 57 stratigraphic levels, totaling 217 subsamples (labeled a through d and listed in Table 8) were collected at mean stratigraphic interval of 38 ft. Ranging from the top to the bottom of the core, the stratigraphic spacing ranged from a maximum of 161 ft across the Fox Hills sandstone, to a minimum of 2.5 ft at the critical Pierre Shale interval at the bottom of the core.

A pilot set of 20 samples (76 subsamples) were collected from the top to the bottom of the core and processed in a single run using a combined thermal and alternating field (AF) demagnetization procedure. The samples were measured at room temperature (NRM), then heated in two steps at 125 and 150°C to remove any hydrous iron oxides that may be carrying a spurious signal, and finally subjected to five step-wise alternating field demagnetization steps of 5.0mT, 7.5mT, 10.0mT, 12.5mT, and 15.0mT. Statistical analysis of these samples showed that a consistent remnant magnetization could be measured. This is believed to be a primary detrital remnant magnetization (DRM) representative of the original paleomagnetic field at the time the samples were deposited.

A final set of 34 stratigraphic levels (93 subsamples) were collected from levels in the core where there were gaps in the paleomagnetic sampling sequence, or where there was some doubt as to the polarity of the interval. The samples were run using the same combined thermal and alternating field (AF) demagnetization procedure.

c. Stepwise alternating-field demagnetization

A third suite from 12 stratigraphic levels (46 subsamples) was processed using just a stepwise AF demagnetization procedure with no thermal steps. No difference could be observed in the DRM from adjacent samples demagnetized with and without the two thermal steps, so the remaining samples from 25 stratigraphic levels were demagnetized the same way in six AF steps (NRM, 5.0mT, 7.5mT, 10.0mT, 12.5mT, and 15.0mT). By the 15.0mT step almost all the samples were completely demagnetized.

Results

Because the core only has up-down orientation data, the measured declination that was aligned with the arbitrary witness mark could only be used to compare the orientation of subsamples measured from within a single stratigraphic level. But in this way the within-site orientation could be subjectively used to evaluate the consistency of the subsamples from each level.

The inclination data from the AF demagnetized samples were processed in a spreadsheet, and a simple mean calculated for each subsample from three to four individual demagnetization steps that maintained a consistent orientation. If there were not at least three samples successfully measured from each stratigraphic level, then the data were discarded and are not shown. Samples were lost due to operator error, and breakage. If there were three or four samples then a mean inclination for those stratigraphic levels could be calculated. The calculated mean inclinations for each stratigraphic level are shown in Table 8. If the range of inclinations at each stratigraphic level did not lie in the same hemisphere then the data were discarded from further analysis and a mean was not calculated for that level (see Table 8). The mean inclination for each stratigraphic level and the inclinations of each individual subsample (a through d) are plotted versus downhole depth in figure 17.

Overall the data are quite consistent. There are 31 levels with a positive mean inclination, and 18 levels with a negative or reversed inclination. The mean positive (normal) inclination throughout the entire core is 52.4 ° and the mean negative (reversed) inclination is –41.1 °. The calculated standard deviations for both positive and negative inclinations are the same at 13.4 °, and the inclination values have an almost identical range from, and +74.3 ° to +22.1 °, –73.2 ° to –14.7 ° respectively. The conclusion that can be drawn from these data are that the normal and reversed inclinations are only approximately antipodal to one another, because the reversed directions are in general some 11° shallower than the normal directions.

When all the data were plotted in the inclination diagram shown in figure 17, there was one level that contained an anomalous single-site reversed sample. Adjacent samples were run and were found to be normal in polarity. The core sample from this level is believed to have been inverted at some point during sample handling. The discarded level is clearly identified in Table 8 by the label "REMOVED" in the mean inclination column and was removed from further analysis.

A single reversed sample was measured in an area of mixed polarity near the bottom of the core at 2147 ft. This interval lies at the level where the paleoenvironment shifted from the marine to terrestrial as the Cretaceous Seaway regressed from the western interior of the US. At the same level at Red Bird, Wyoming, there is a similarly anomalous interval that corresponds to the nearshore marine environment. At Red Bird this level is glauconitic and almost certainly has been overprinted. In the Kiowa core this interval has been extensively re-sampled and re-measured, but has been found to contain multiple levels of mixed polarity. In the interpretation shown in figure 17 the top of C31r is projected to lie at approximately 2100 ft, and in the future additional samples will be measured from this interval to try and better define the polarity.

Reversal sequence

Visual inspection of figure 17 shows that there are nine distinct polarity intervals in the full length of the Kiowa core. In figure 17 they are labeled from R1 to R5, and from N1 to N4.

a. Mixed polarity interval R1 to R2

The basal reversal, R1, is defined by two reversed levels that lie close to the base of the Kiowa core. This level contains a normal polarity interval N1, which is an interval of mixed polarity made up of four normal samples and four inconsistent samples for which no average direction could be ascertained (see label 1, fig. 17).

At this stratigraphic level the core lies just below the distinctive sandstone facies of the Fox Hills, in the uppermost part of the Pierre Shale. In surface exposures along the western edge of the Denver basin the top of the Pierre Shale is known to lie in the ammonite range zones of *Baculites clinolobatus* and *Hoploscaphites birkelundi.* Magnetostratigraphic analysis of the Red Bird section in eastern Wyoming (Hicks and others, 1999) has shown that *B. clinolobatus* lies in the middle of C31r and the top of this ammonite range zone at Red Bird has been dated isotopically at 69.57 ± 0.37 Ma (Hicks and others, 1999).

The top of the R2 interval is projected to lie at about 2110 ft in the core and its position is known to within ± 38 ft (Table 8). The age control from the ammonite biostratigraphy indicates that this reversal is the top of C31r, which has been dated at 69.01 Ma by extrapolation from isotopically dated ash beds in the Red Bird magnetostratigraphic section (Hicks and others, 1999; labeled 5, fig. 17). Plotted on figure 17 (label 2) are the ages for *B. clinolobatus* (69.57 Ma), the extrapolated age of the top of C31r (69.01 Ma), and the age of the top of C31r after the time scale of Cande and Kent (1995; 68.737 Ma; time scale referred to as CK95 in the following text). The extrapolated age of the boundary and the age estimate of CK95 are very close, lying within 0.27 Myr of each other.

b. Normal polarity interval N2

The normal polarity interval above R2 ranges from the uppermost part of the Pierre Shale at 2110 ft through the Fox Hills and overlying Laramie to a level of 1182 ft in the lower third of the D1 synorogenic stratigraphic interval (see label 3, fig. 17). The total thickness of the N2 polarity interval is 928 ft, and the top can be placed with a precision of ± 21.2 ft (Table 8). The N2 interval is bracketed above and below by two calibration points. As defined in the section above the ammonite range zones of *B. clinolobatus* and *Hoploscaphites birkelundi* define the age of the Maastrichtian marine sediments of the Pierre Shale at the base of the N2 interval. The K-T boundary interval has been placed palynologically in the core at between 878-880 ft and lies above N2 in a reversed polarity interval R3 (see label 4, fig. 17). The K-T boundary has been dated at 65.51 Ma (Hicks and others, 2001).

In this time period between 69.01 and 65.51 Ma there are two possible normal intervals that can be correlated to N2, C30n and C31n. But they are separated by only a very short reversed polarity interval, C30r, which is only 125,000 years in duration (Cande and Kent, 1995). Because it is so short, C30r is rarely encountered in terrestrial magnetostratigraphic sequences, therefore N1 most likely ranges from the base of C31n to the top of C30n and C30r is not found in the sequence. The sedimentation rate for this interval is calculated at approximately 292 ft/Myr of compacted sediment (Table 8).

c. Reversed polarity interval R3

The reversed polarity interval R3 lies in the middle of the D1 synorogenic strata interval (fig. 17) and ranges from 1182 ft to 879 ft, an interval of 303 ft of core. The Cretaceous/Tertiary boundary in the Kiowa core has been placed palynologically at between 878 and 880 ft, which conclusively identifies R2 as C29r. The K-T boundary is known globally to lie within the upper half of C29r (D'Hondt and others, 1996). In the Kiowa core the boundary lies within 2 ft of the projected top of R2 at 879 ft, and the reversal boundary R3/N3 is known to within ± 7 ft, meaning that the K-T boundary and the top of the C29r reversal are indistinguishable (Table 8).

Our conclusion is that the K-T boundary, as defined palynologically in the Kiowa core, lies at the top of C29r. This indicates that there may have been a hiatus or a period of erosion in the earliest Paleocene in this part of the Denver Basin (fig. 17) which removed at least 300 kyrs of C29r.

A revised age estimate for the K-T boundary interval of 65.51 ± 0.10 Ma (see label 4, fig. 17) has been obtained by normalizing the most recently published isotopic dates for the boundary to a standard monitor age of 28.02 Ma for the Fish Canyon Tuff and 28.32 Ma for the Taylor Creek Rhyolite. Orbital chronology gives very precise estimates for the duration of C29r that range from 570 kyr to 673 kyr, but the most modern published estimate (D'Hondt and others, 1996) assigns an age of 603 ± 26 kyr for the whole of C29r, with 333 ± 20 kyr from the base of C29r and the K-T boundary, and 270 ± 17 kyr for the interval from the K-T to the top of the chron. By extrapolating from the palynological K-T boundary to the base of C29r and employing the 333 kyr precessional age for the interval of C29r that lies below the K-T, the age of the C30n/C29r reversal is estimated to be 65.84 Ma (fig. 17).

The calculated sedimentation rate for this interval is approximately 911 ft/Myr of compacted sediment (Table 8), which is a 300% increase over the underlying interval defined by N2. The implication is that the Fox Hills, Laramie and the lower part of the Dawson (D1) accumulated at a relatively low and steady rate as the Cretaceous Seaway regressed from the region, and that there was a marked increase in sedimentation rate near the end of the Maastrichtian in the middle part of the D1 as the Laramide orogeny developed along the Rocky Mountain front and subsidence accelerated in the adjacent foreland basin.

d. Normal/reversed/normal polarity interval N3 to N4

N3 lies in the upper half of the D1 synorogenic strata and ranges from 879 ft to a projected level of 628 ft with a precision of ± 39 ft, an interval of 251 ft. The two polarity reversals N3/R4 and R4/N4 define a short reversed interval in the upper part of the D1 sequence (see label 5, fig. 17). The top of N4 coincides almost exactly with the position of the D1/D2 paleosol that has been logged at 340 to 354 ft in the core (fig. 17).

The top of N4 is projected to lie at 351 ft which coincides exactly with the paleosol level and the contact of D1 and D2 (see label 6, fig. 17). This indicates that the N4/R5 reversal is an artifact caused by either a hiatus or active period of erosion at the level of the paleosol. Therefore both the base and top of this N3/R4/N4 interval are marked by hiatuses or erosional levels. The interval is bounded by the age of the K-T boundary below, and above by an isotopic age of 64.13 Ma obtained from an ash that lies just beneath the level of the paleosol (fig. 17).

This interval can be broadly correlated to that part of the GPTS that spans from C29n to C28n. The CK95 geomagnetic polarity time scale (GPTS) that ranges from the Maastrichtian through the Paleocene was calibrated using an age for 65.0 Ma for the K-T boundary. For this reason their age interpolation for the interval from C29n to C28n is approximately 0.5 Myr less than we would estimate. In figure 17 we show the age estimates for the CK95 time scale assuming that the sequence N3/R4/N4 corresponds to C29n through C28n. The CK95 time scale assigns an age that is somewhat older than the age we have measured, which is based on the 64.13 Ma isotopic age beneath the paleosol and extends to the base of C29n which is dated at 65.24 Ma (shown by the black hashed line in fig. 17). This age for the base of C29n is derived from the age of the K-T (65.51 Ma) and the precessional age of the upper part of C29r (333 kyr). The difference between this estimate and CK95 increases up section. The problem is compounded by the fact that there is an indeterminate amount of time missing from the K-T boundary hiatus and from the overlying paleosol. Nevertheless the reversal pattern measured does correspond well to the C29n to C28n interval, and this is the interpretation that we show in figure 17.

e. Reversed polarity interval R5

R5 extends from the top of the D1/D2 paleosol at approximately 351 ft to the uppermost sample measured in the core at 83 ft. R5 lies wholly within the Dawson (D2) stratigraphic interval. As the base of R5 lies on a hiatus or even an erosional disconformity, marked by the deep weathering profile of the paleosol sequence, and the top of the reversal is not found, then R5 is a fragment of a currently unidentified reversed polarity interval. This polarity interval is tentatively correlated to some part of C24r based on an Eocene age for D2 cited by Soister (1978b).

Conclusions

The Kiowa core is dominated by terrestrial sediments, and we have measured a number of hiatuses or disconformities (fig. 17) that are invariably part of a terrestrial sedimentary sequence. But our preliminary conclusions indicate that the core can be correlated with a high degree of confidence to that part of the GPTS that ranges from the top of C31r to C24r, or from the Maastrichtian to the Early Eocene. Thus the core encompasses a time period of approximately 15 million years from 69 to 54 Ma.

If the sequence is plotted on a time rather than a stratigraphic scale, then the amount of time missing in the sequence becomes apparent (fig. 18). This figure is based on the interpretation and ages described above and in figure 17. There is an obvious diachroneity between the isotopic age obtained below the paleosol and the age estimate for this polarity interval based on CK95. This is to be resolved in future studies of the ash layer and by a recalibration of the time scale to a revised K-T boundary age of 65.51 Ma.

Mineralogy and Petrography

Methods

Thin sections and Scanning Electron Microscope (SEM) photomicrographs of sandstone samples from the Kiowa core were used to determine the character and likely source terrain for the sandstone layers. Table 9 contains data derived from point-count analysis of over 40 thin sections made from sandstones from the core and figure 19 illustrates a representative SEM view of the disaggregated sand grains.

Results

a. Texture

Average visible mean grain sizes increase consistently upwards from a low value of 0.09 mm in the Pierre Shale sandstones to 0.18 mm in the Fox Hills Sandstone, 0.35 mm in the Laramie Formation (only one sample), 0.37 mm in the D1 sequence, and 0.56 mm in the D2 sequence. However, although grain sizes vary over only a limited range in the Pierre Shale (0.06 to 0.1 mm) and Fox Hills Sandstone (0.07 to 0.35 mm), they display wide variations in the D1 (0.09 to 1.5 mm) and D2 sequences (0.15 to 1.5 mm).

Average visible sorting levels are relatively consistent in the Pierre Shale (average of 0.42 phi and range from 0.38 to 0.45 phi) and Fox Hills Sandstone (average of 0.45 phi and range from 0.38 to 0.6 phi). The only sample from the Laramie Formation has a sorting value of 0.45 phi. Average sorting values increase significantly in D1 (0.63 phi), and D2 (0.79 phi) but range widely in both units (0.4 to 1.1 phi in the D1 sequence and 0.5 to 1.2 phi in the D2 sequence).

Grain size is commonly a major control on composition with certain components being relatively abundant in the finer size ranges while others dominate the coarser size ranges. Typically feldspars, dolomite, and micas tend to be concentrated in the coarse silt to fine sand size ranges, whereas quartz and rock fragments (including chert) tend to be most abundant in the coarser size ranges. To evaluate the influence of provenance on sandstone composition, grain size controls must be taken into account.

b. Composition

Quartz-feldspar-lithic proportions: The quartzose content is highest in sandstone beds in the Fox Hills Sandstone (72 percent) and the Pierre Shale (63 percent). Quartzose content drops off to only 30 percent in the Laramie Formation (based on one sample) and then increases to 51 percent in the D1 sequence and to 55 percent in the D2 sequence. The feldspathic content is approximately the same in the Fox Hills and Pierre (14 and 13 percent respectively), increases slightly in the Laramie (14 percent), increases in the D1 sequence (18 percent), then increases significantly in the D2 sequence (33 percent). Lithic components are moderately high in the Pierre (24 percent), about half that in the Fox Hills (11 percent), quite high in the Laramie (56 percent, only one sample), high in the D1 sequence (31 percent) and low in the D2 sequence (12 percent).

Quartzose components: Monocrystalline quartz is relatively high in both the Fox Hills and Pierre (51 and 46 percent respectively), low in the Laramie (21 percent), and moderate in the D1 and D2 sequences (35 and 36 percent, respectively). Polycrystalline quartz (all grains with greater than 1 crystal subunit) content is low in the Pierre (3 percent) and much higher in the Fox Hills (8 percent). The larger amount of polyquartz in the Fox Hills may be largely attributable to the increased average grain size of these sandstones. Polyquartz is low in the Laramie (4 percent, only one sample), moderate in the D1 sequence (6 percent), and highest in the D2 sequence (10 percent). Higher levels of average polyquartz tend to correlate strongly with increased grain size in most units. The relatively high polyquartz content in the Fox Hills compared to the coarser D1 and D2 sandstones is probably produced by a greater input of low-grade metasediments during deposition of this unit.

Chert content is highest in the Fox Hills (8 percent) and Pierre (7 percent) with the reduced content in the latter probably attributable to the finer average grain size of these sandstones. Chert is low in the Laramie (3 percent) but only one sample was available for comparison. Chert is higher in the D1 sequence (4 percent) reflecting a stronger sedimentary source than in the Laramie. Sandstones in the D2 sequence average only 0.1 percent chert, reflecting the very low sedimentary input for this unit. It is possible that some of the chert in the D1 is actually finely crystalline polyquartz rather than chert.

Feldspathic components: Plagioclase content is comparable in the Fox Hills (4 percent) and Pierre (5 percent) with the higher content in the latter probably related to the finer grain size of these sandstones. Surprisingly, plagioclase is absent in the Laramie (based on one sample), which may reflect the relatively silicic and potassium-rich nature of the volcanics sourcing this sandstone. Plagioclase is minor in the D1 sequence (3 percent), and this may also reflect a high silicic/potassium-rich volcanic source for many of the sandstones in this unit. In the D2, sequence plagioclase jumps to 8 percent and indicates a more basic composition for the plutonics sourcing this unit. Potassium feldspar is moderate in the Fox Hills (8 percent) and Pierre (7 percent) and significantly higher in all three of the younger units (averages of 12 percent in both the Laramie and the D2 sequence). The much higher potassium feldspar content in the upper three units reflects the higher input of locally sourced potassium feldsparbearing volcanics and plutonics for these sandstones. Granitic fragments increase consistently from less than 1 percent in the Pierre to 3 percent in the D1 sequence. Granitic fragment content jumps to 11 percent in the D2 sequence, strongly reflecting the high plutonic input for these sandstones.

No gneiss fragments were encountered in any of the sandstones analyzed. This strongly suggests that high-grade metamorphics typical of the Front Range foothills north of the Castle Rock area were not a source of debris for any of the sandstones studied.

Lithic components: Total ductile grain (micas, mudstone fragments etc.) content varies widely between units. It is high in the Pierre (13 percent) largely due to its high content of micas and organic fragments. Ductiles are much lower in the Fox Hills (7 percent) with most being micas, organic fragments, and shale/mudstone/argillite fragments. Ductiles increase to 12 percent in the D1 sequence as a result of a high content of micas and mud/clay pellets. They are also high in the D2 sequence sandstones (11 percent) due largely to their high mica content.

Carbonate fragments are absent in the D2 sequence and Laramie sandstones, and comprise only a minor component of most D1 sandstones (1 percent) and Fox Hills sandstones (2 percent). However, they are considerably more abundant in sandstones of the Pierre (6 percent) with much of this increase possibly reflecting the decreased grain size of these sandstones and increased sedimentary input in the Pierre-Fox Hills interval. All of the carbonate grains encountered are dolomite fragments. Heavy minerals are trace components in most samples.

Volcanic fragments are virtually absent in D2 sandstones (1 percent) and only a very minor component in the Fox Hills (2 percent) and Pierre (2 percent). They are much more abundant in the D1 sequence (17 percent) and Laramie (50 percent, only one sample). The very low content of these components in D2 reflects the lack of volcanic input during deposition of these sandstones.

c. Trends within stratigraphic units and with grain size

Chert content tends to increase from the base of the Pierre, where it is 3 percent, into the lower Fox Hills, where it reaches a high of 12 percent. It then decreases rapidly in the lower part of D1, where it is absent in a sample at a depth of 1528 ft. The decreasing trend is not entirely consistent as minor stratigraphic variations occur within this interval. The decrease in chert content in the lower part of D2 occurs despite the increased grain size of the sandstone in the upper Fox Hills and lower part of D1. Chert commonly exhibits a very strong positive correlation with grain size; for example, this relationship has been observed in the Permian through Lower Jurassic sandstone of the Alaska North Slope, Lower Cretaceous conglomerate and sandstone in the Alberta Basin, and in the Lower Cretaceous Frontier Formation of the Green River and Wind River Basins (M.D. Wilson, pers. comm., 2000). Such a relationship is not observed in the bulk of the sandstone penetrated in the Kiowa well, suggesting that provenance rather than grain size is the stronger influence on the composition of these sandstones. Chert content increases in the middle portion of D1 (at depths of 937 to 1,350 ft) to 14 percent and 21 percent in two samples. It then decreases to very low levels (less than 1-2 percent) in the upper part of the D1 sequence at depths of 429 to 619 ft. Chert is absent in the uppermost D1 sample, and in all but the uppermost D2 samples, where it occurs in trace amounts (0.5 percent). Chert may have been derived from reworking of clastics in Mesozoic and Paleozoic rocks and from the lower Paleozoic carbonates in the Pikes Peak area.

Carbonate fragments (dolomite fragments only) are absent in all but one sample (0.5 percent at a depth of 524 ft) down to a depth of 623 ft. Dolomite content then increases to 4-7 percent in two samples at depths of 852 and 976 ft. Dolomite is also present in trace to very minor amounts (1-2 percent) in samples at 1,177 and 1,246 ft, although two samples at depths of 1,060 and 1,061 ft are devoid of dolomite. Dolomite is absent throughout the lower part of D1 and the Laramie and upper Fox Hills down to a depth of 1,963 ft. At this depth it is present in significant amounts (3-9 percent), and also in all deeper samples. The simultaneous occurrence of large amounts of chert and minor dolomite in the medial portion of the D1 sequence suggests that unroofing of lower Paleozoic carbonates may have occurred at this time. The presence of chert in lesser amounts in deeper zones in the D1 sequence, but lack of dolomite, may indicate that these sandstones were derived from overlying Paleozoic and Mesozoic strata containing relatively modest to low chert content. The combined occurrence of minor to moderate chert and dolomite in the lower Fox Hills and Pierre suggest that these sandstones were derived from a chert-bearing, carbonate-rich source terrain such as the upper Paleozoic sedimentary rocks in the Sevier thrust belt, in Utah and Wyoming.

The percentage of volcanic fragments varies significantly in the section analyzed. Only trace to very minor amounts of silicic volcanics occur in the D2 sequence and no basic volcanics are present in any of the D2 sequence samples. Silicic volcanics are present in trace to minor amounts in the Fox Hills and Pierre samples and basic volcanics occur in trace to very minor amounts in only one sample in each of these two units. Silicic volcanics dominate many lithic-rich sandstones in the D1 sequence and the Laramie Formation sample. These sandstones tend to occur in the lower D1 (1,458-1,635 ft) and in the uppermost D1 (368-524 ft). Volcanic content is low however, in the finer grained sandstones throughout D1 regardless of stratigraphic position (0.06-0.15 mm average visible mean grain size).

Basic volcanics are absent in many D1 sequence samples but tend to occur in trace to very minor amounts in samples containing large amounts of silicic volcanics. The low content of basic volcanics throughout the section suggests that silicic volcanics were the main type of volcanic sourcing the sandstones analyzed. The silicic volcanics tend to contain large amounts of very fine sanidine (?) and quartz and appear to have phenocrysts scattered sparsely through a cryptofelsitic groundmass. Phenocrysts in the silicic volcanic fragments tend to be primarily plagioclase and biotite, though occasionally opaque heavy minerals, apatite, and possible amphibole phenocrysts are present. The more unstable phenocrysts tend to be altered to smectite or dissolved. Mafic constituents of these fragments are typically minor components and have been altered to smectitic or chloritic clays. Most of these silicic volcanics are probably rhyolites or dacites.

Apatite Fission Track Analysis

Ten samples were taken from the Kiowa core for fission track analysis at the New Mexico Institute of Mining and Technology. Fission tracks are microscopic crystal lattice disruptions caused by radioactive fission events. The crystal lattice disruptions are made visible by acid etching. In the mineral apatite these lattice disruptions anneal at about 60-70° C. By counting the number of tracks and the amount of radioactivity present in a given crystal (together with an assumed decay rate), one can compute the time elapsed since the rock cooled below the annealing temperature (Kelley and Chapin, 1997).

The samples from the Kiowa well (fig. 20a) indicate an age of cooling that generally ranges from 54 to 70 million years, ages that correspond to the Laramide orogeny. Some apatite crystals give significantly older dates (see for example samples from 1,394 and 1,715 ft). These older ages are thought to have been derived from crystals eroded from the crest of the uplifting Rocky Mountains.

Zircon Fission Track Analysis

Ten samples were mounted in Teflon, polished, and etched in NaOH/KOH at 230°C for the times shown in table 10. Age histograms are shown in figure 20b. The samples contained zircon populations that had various etching characteristics. The mounts were cut in half and each half was etched for a different amount of time in an attempt to attain optimum etch conditions for each population. In this set of samples, mounts 1 and 2 were etched for the same amount of time.

The zircons were placed in a reactor package with Fish Canyon zircon age standards and Corning (CN-5) fission-track glass standards. The ages were calculated using the zeta calibration (422 ± 67 for zircon). The neutron flux for the reactor run was determined from glass standards and the accepted ages of the zircon standards.

When the samples were counted, the mounts were systematically scanned. Each grain encountered was evaluated. In many cases the zircon grain was metamict; in other words the grains were so old that radiation damage has destroyed the crystal structure. These grains were likely derived from the Proterozoic basement. Many of these grains are subhedral, although rounded metamict grains were observed in D1 sediments below 1395 ft. Some grains were over-etched and some were under-etched, and thus not dateable. Mounts that were etched for a short amount of time in order to best etch old zircons had large numbers of unetched grains, while other mounts etched for longer times to reveal the tracks in younger grains had many over-etched grains. Datable grains are well-polished and etched, so that tracks parallel to the c-axis are easily detectable. The number of metamict grains, likely reflecting the contribution from the basement or recycled Proterozoic grains, as well as the number of over-etched, under-etched, and dateable grains from each mount is recorded in table 10. The relative percentage of volcanic grains, distinctive yellow euhedral to brownish-yellow subhedral grains with high uranium concentrations and fission-track ages in the 60-90 Ma range is also indicated. The relative percentage of metamict versus volcanic grains varies throughout the D1 package.

TEMPERATURE LOGGING

Temperatures were measured in the Kiowa well for two reasons. First, temperature data in the southern Denver Basin are scarce and the effects of the aquifers on the temperature distribution in the basin are not well documented. Second, evaluation of the temperatures in the well is needed for proper interpretation of apatite fission-track data from the core samples.

Methods

Temperatures in the Kiowa well were measured four times. The temperature measurements were obtained using equipment calibrated in meters while most core and drilling data were measured in feet. Thus, measurements discussed here are reported in the units used during data acquisition. A conversion table is provided at the beginning of this report.

The first logging run took place about 24 hours after the last section of core had been extracted from the well, about an hour after the geophysical logs were run (table 11 and fig. 21). Drilling a well disturbs the ambient temperatures of the rocks. Fluids used during drilling heat up the upper section of a drill hole and cool the deeper portions of a well. Consequently, immediately after drilling, the temperatures in the borehole are out of thermal equilibrium, and it can take up to a year for the temperatures to return to normal.

Although the Kiowa well was out of thermal equilibrium, temperature logging commenced immediately after drilling because the well was going to be plugged back to a depth of 734 ft. The first temperature log was measured by taking readings every 5 m using a calibrated thermistor attached to about 2,500 m of cable. The thermistor was lowered into the well using a hand crank. Data from the top 1,837 ft were collected inside the drill pipe and temperatures were measured in open hole below that point. The drill pipe was left in the hole above the top of the Fox Hills Sandstone to keep the hole from collapsing during logging. The fluid level in the hole was about 15 m below the ground surface at the time of logging.

The hole was completed as a monitoring well by setting casing to a depth of 734 ft in late April 1999. The upper part of the well was re-logged approximately three months after the initial logging run using a truck-mounted system. Data were collected every 0.1 m (table 12 and fig. 22). The water level in the hole was ~100 m at the time of second logging run. Monitoring equipment in the hole prevented logging below a depth of 157 m. The well was logged a third and fourth time at 5 to 10 m intervals using the hand-crank logging equipment approximately six months and one year after the well was completed. The water level was at a depth of about 100 m during the third and fourth logging runs.

Results

The temperature and geothermal gradient data from the four logging runs are shown in figures 21 and 22. The temperature data from the April 6, 1999 run are surprisingly smooth, given the fact that the hole was just disturbed by drilling and logging. Fluids moving around at the base of the drill pipe caused the rather large disturbance at a depth of 560 m (figures 21 and 22). The relatively high geothermal gradients in the interval between 220 m to 260 m correspond to an interval containing many lignite beds.

The truck-mounted logging system has a hard time equilibrating in air, so there is an offset in the temperatures measured on July 6, 1999 at the water table. Note that, below the water table, the temperatures apparently decreased 3°C in the upper part of the well between the April 1999 and July 1999 runs. This observation may be due to a real cooling effect or it may reflect a difference in calibration between the two pieces of equipment used to make the measurements. Temperatures recorded during the third and fourth runs are cooler than those recorded during the first run, as expected, but are significantly warmer than those recorded during the second run in July 1999. Since the well was not disturbed between July 1999 and October 1999, it is likely that the differences in temperature recorded are due to calibration. Despite the absolute differences in temperatures recorded in different logging runs, the relative differences in temperature (i.e., the geothermal gradient) measured by the two systems track each other fairly well, particularly at depths below 120 m. The higher gradient recorded at a depth of 140 m is in an interval of mudstone and minor lignite, whereas lower gradients recorded in intervals above and below this point are in silty mudstone intervals. Mudstone facies dominate the sediments below 155 m. The well cooled only about 0.1°C between October 1999 and April 2000; thus the fourth log represents a near-equilibrium log.

The initial, non-equilibrium log of the Kiowa well was compared with a partially equilibrated log from the Castle Pines well to the west (Robson and Banta, 1993) (fig. 23). The temperatures in the Kiowa well are nearly 9°C warmer than the Castle Pines well at a depth of 680 m. The deeper portions of the Kiowa well are not as far out of equilibrium as the shallower sections, and the deeper parts of the well will warm during equilibration after interacting with relatively cooler drilling fluids during the equilibration process. A discrepancy in calibration between the logging equipment used in the Castle Pines well and that used in the Kiowa well is a consideration, but there are differences in geothermal gradient between the two wells. The average gradient for the Kiowa well is approximately 31°C/km while the gradient in the Castle Pines well is only 17°C/km. The temperature and gradient distribution may be related to the hydrology of the Denver basin. The Castle Pines well is closer to the recharge part of the basin, and has cooler temperatures and lower gradients, while the Kiowa well may have been heated by waters discharging eastward after the waters were warmed in the deeper parts of the basin.

RADIOMETRIC DATING

Two outcrops east of the Kiowa core were sampled for radiometric dating of mineral grains (sanidine) obtained from beds of altered volcanic ash. These radiometric dates are extrapolated into the subsurface to constrain the interpretation of the paleomagnetic signature in the Kiowa core.

The radiometric dates together with relevant constants are reported in table 13. The mineral grains dated at 64.13 ± 0.21 Ma are from an ash bed located at 39° 24.93' N, 104° 20.26' W on the Haas Ranch, and the grains dated at 65.03 ± 0.25 Ma are from an ash bed located at 39° 16.53' N, 104° 15.47' W on the north side of State Highway 86.

GEOPHYSICAL LOGGING

The geophysical logging was carried out by the Colog Division of Layne Geosciences, Inc. The logging was conducted in three separate runs. The first run spanned from the surface to a depth of 562 ft and was run on March 24, 1999. The second run spanned depths from 550 to 1,797 ft and was run on March 31, 1999. The final logging run spanned depths from 1,797 to 2,256 ft and was run on April 6, 1999.

The following tools were run: caliper, gamma ray, spontaneous potential, resistivity, compensated density, and full waveform sonic. There is a section of hole between 1,412 and 1,864 ft where no resistivity log is available because the lightweight sensor was not able to reach the entire logged interval. A set of logs is included as Plate 1. Selected log traces are portrayed on figure 9 where log data can be directly compared to both core lithology and the core sampling program.

SEISMIC LINE

R.J. Grundy and Associates at EnviroSeis obtained a short seismic line adjacent to the core hole in Kiowa. The seismic line was obtained using Vibroseis techniques and runs from the core location site, east to the county road, then north for about a mile along the side of the road. Selected reflectors are identified on the seismic line. The seismic line is included as Plate 2.

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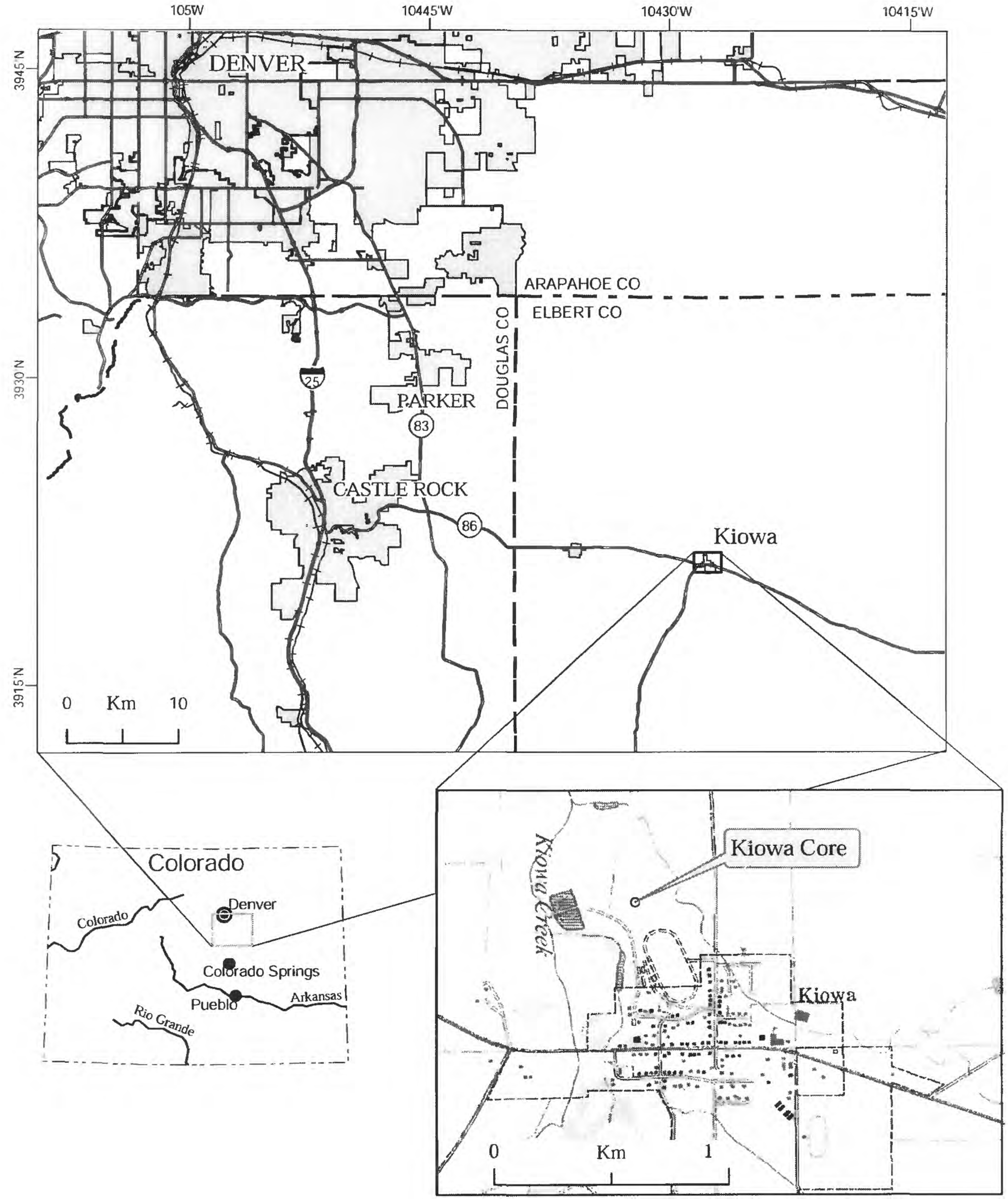

Figure 1 Map showing location of Kiowa core site southeast of Denver, Colorado

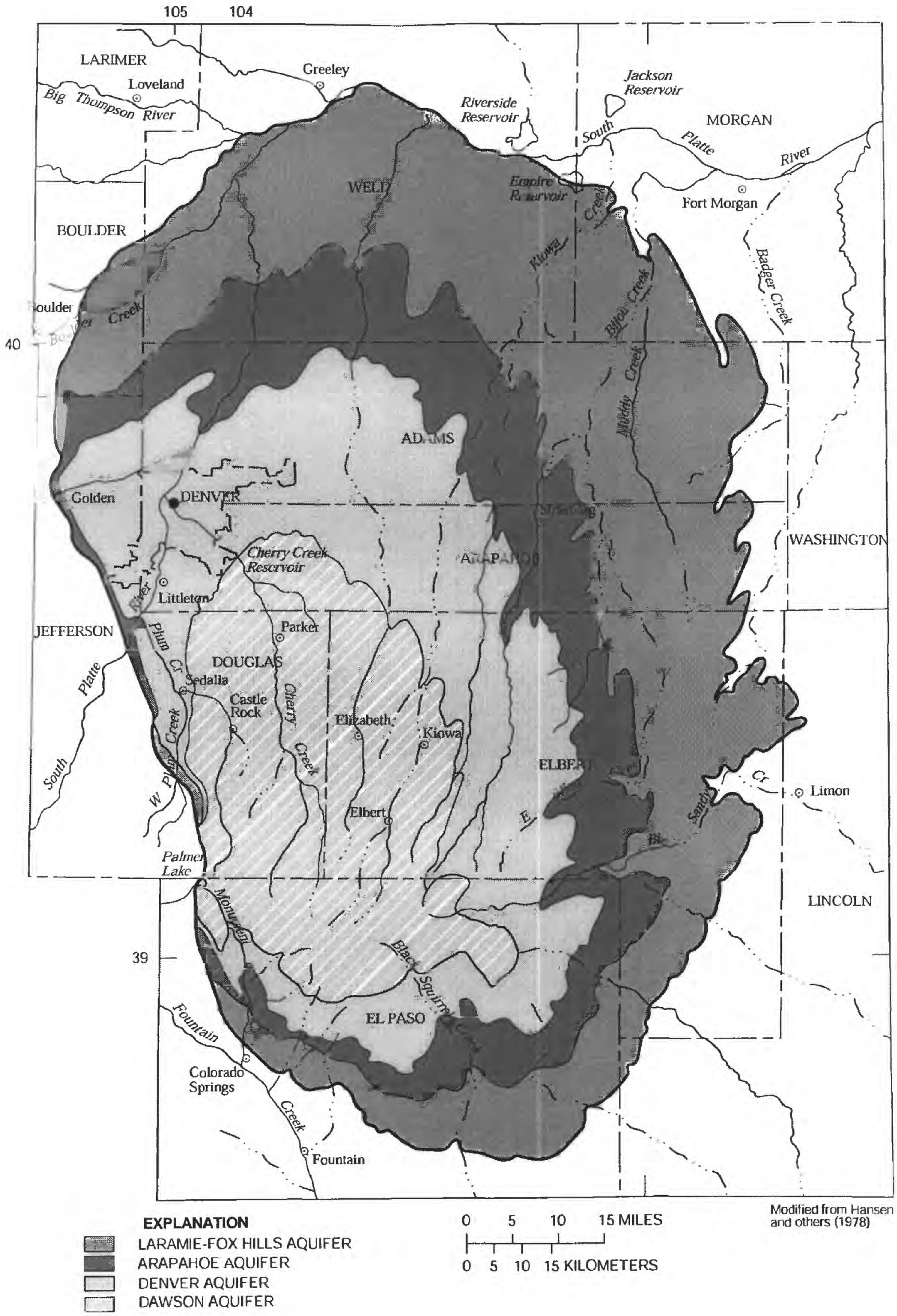

Figure 2 Map showing outcrop pattern of the principal aquifers of the Denver Basin, Colorado

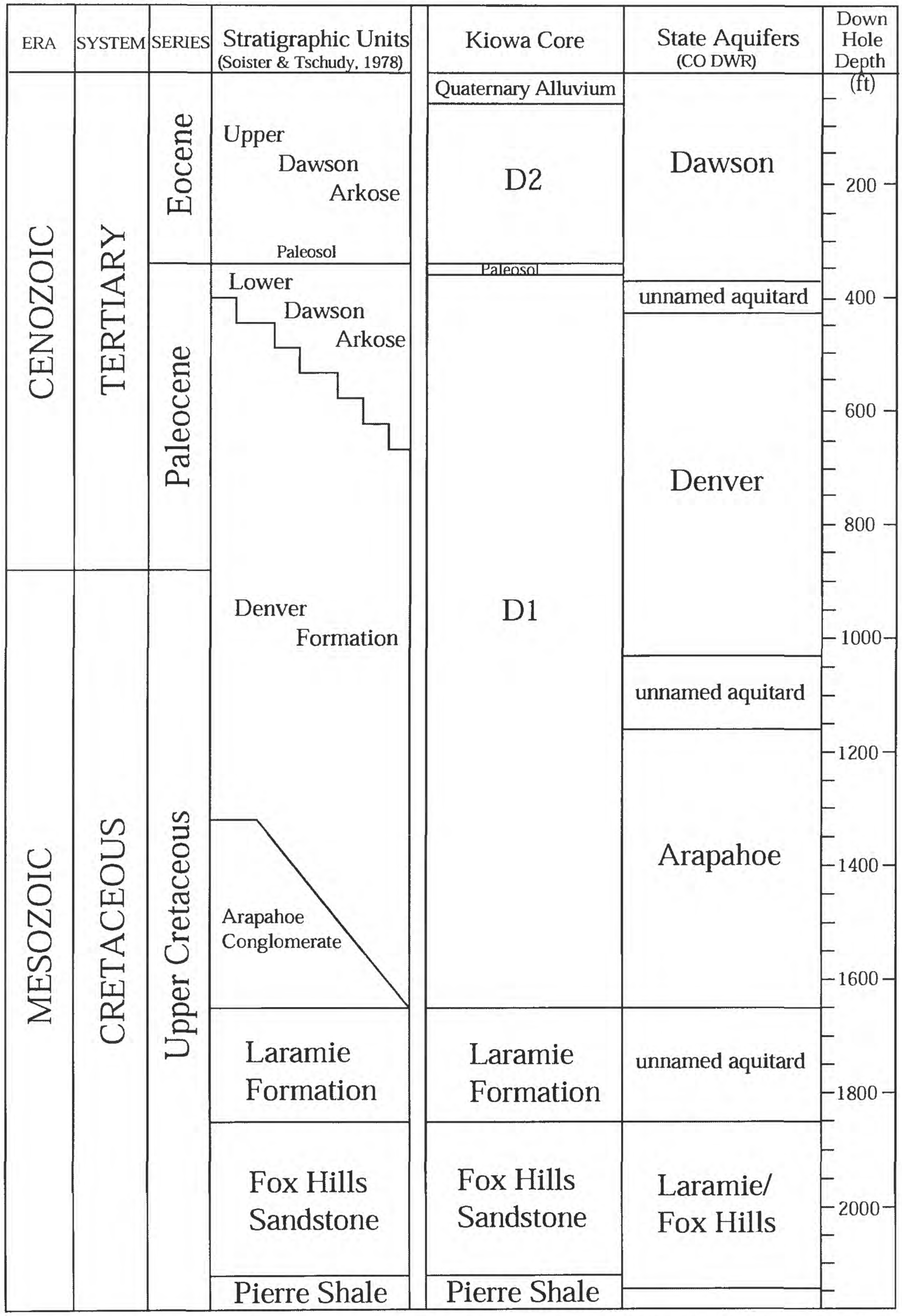

Figure 3 Chart comparing stratigraphic and hydrpgeologic nomenclature in the Denver Basin, Colorado

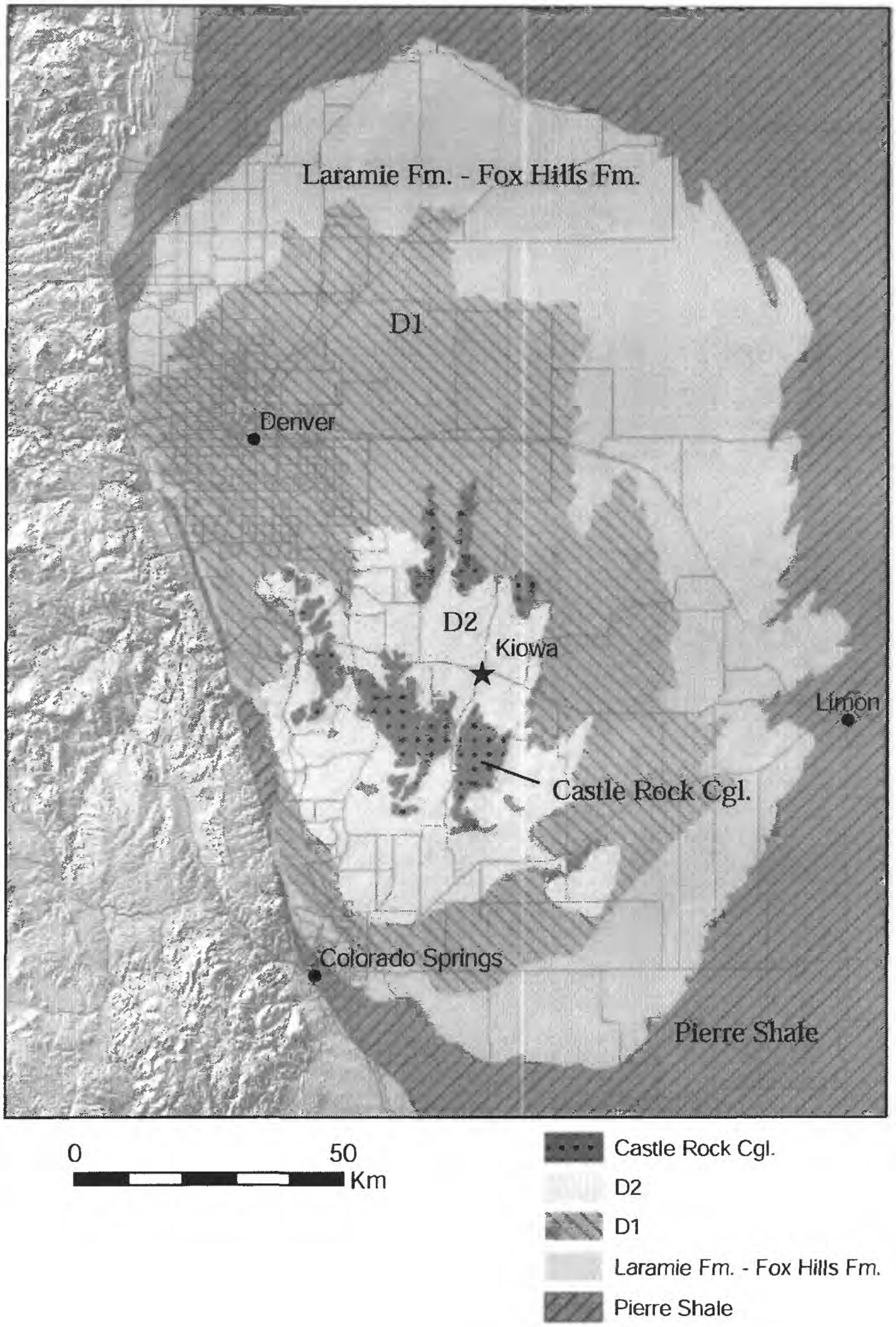

Figure 4 Map showing generalized bedrock geology of the Denver Basin, Colorado

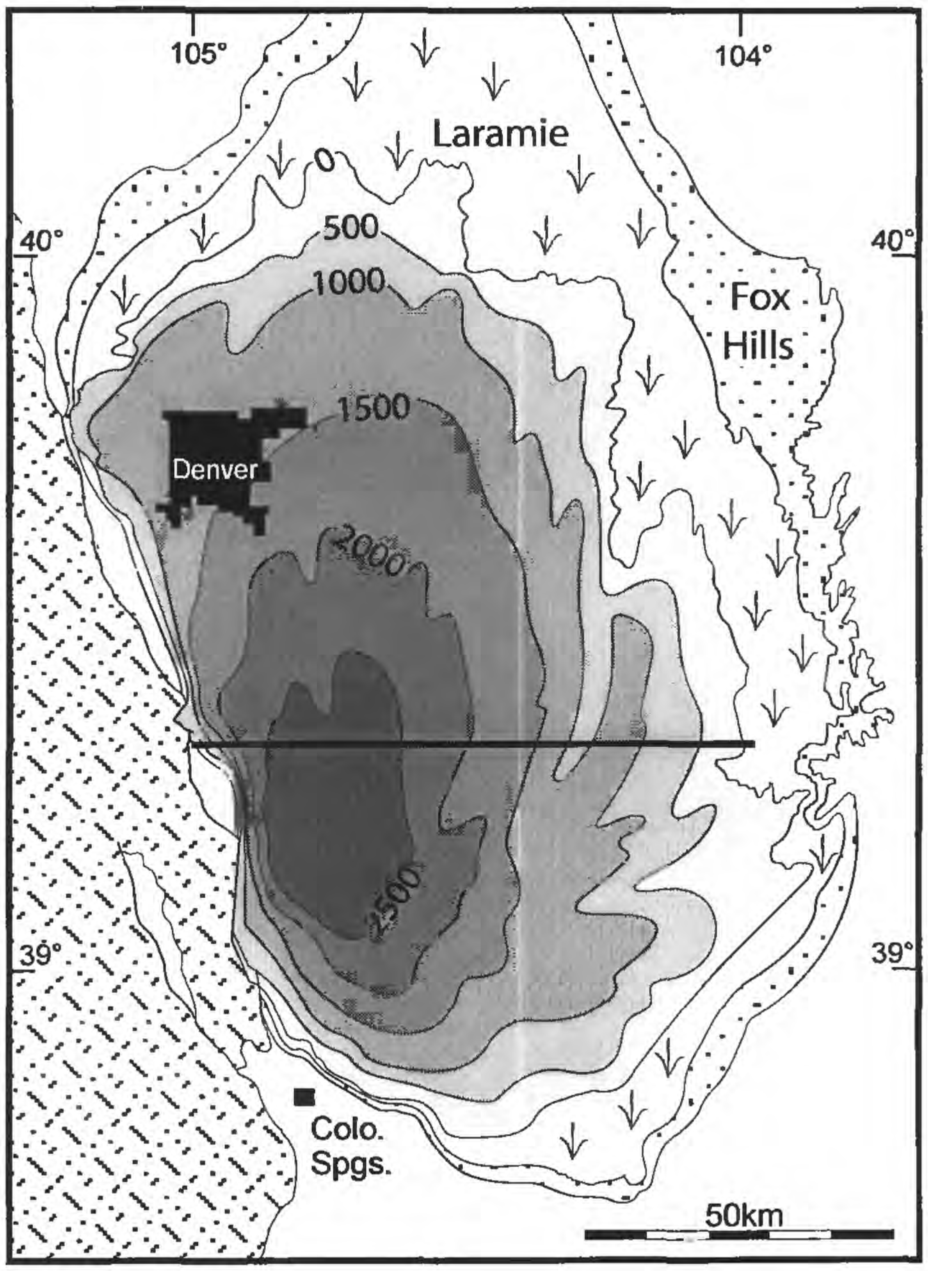

Figure 5. Thickness in feet of synorogenic strata preserved in the Denver Basin

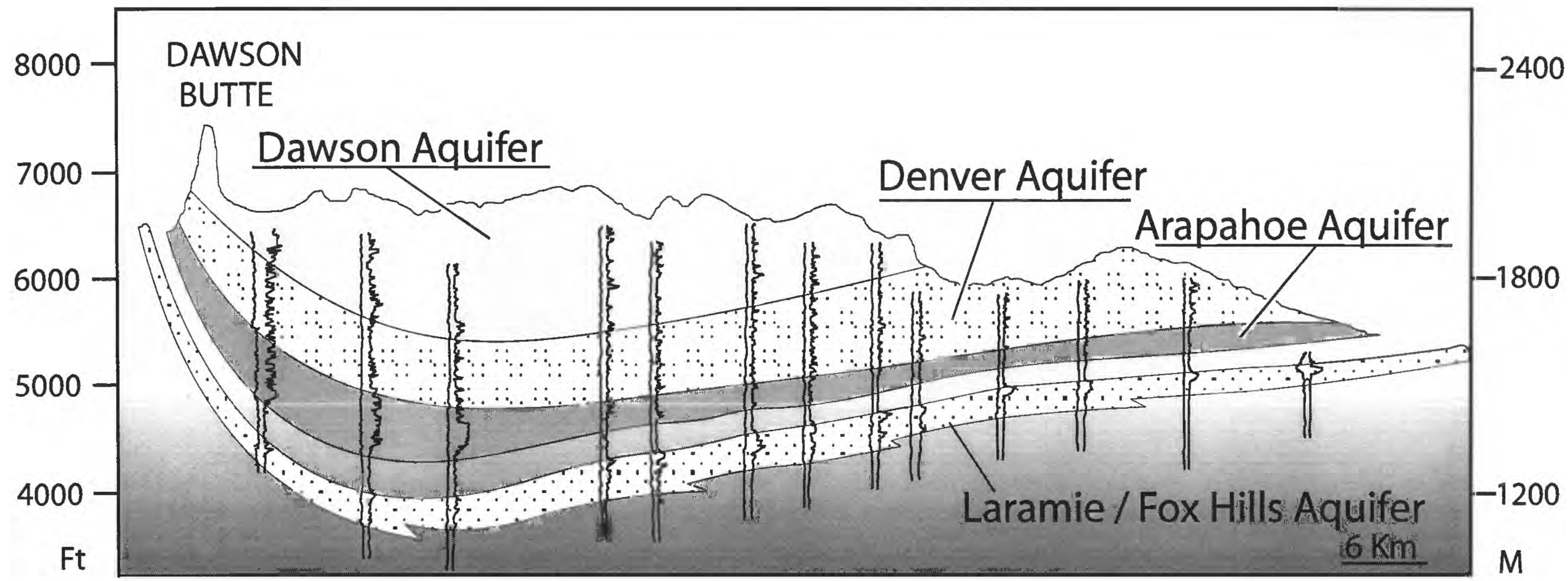

Figure 6 Generalized chart showing the principal aquifers of the Denver Basin, Colorado (location of cross section shown in Figure 5)

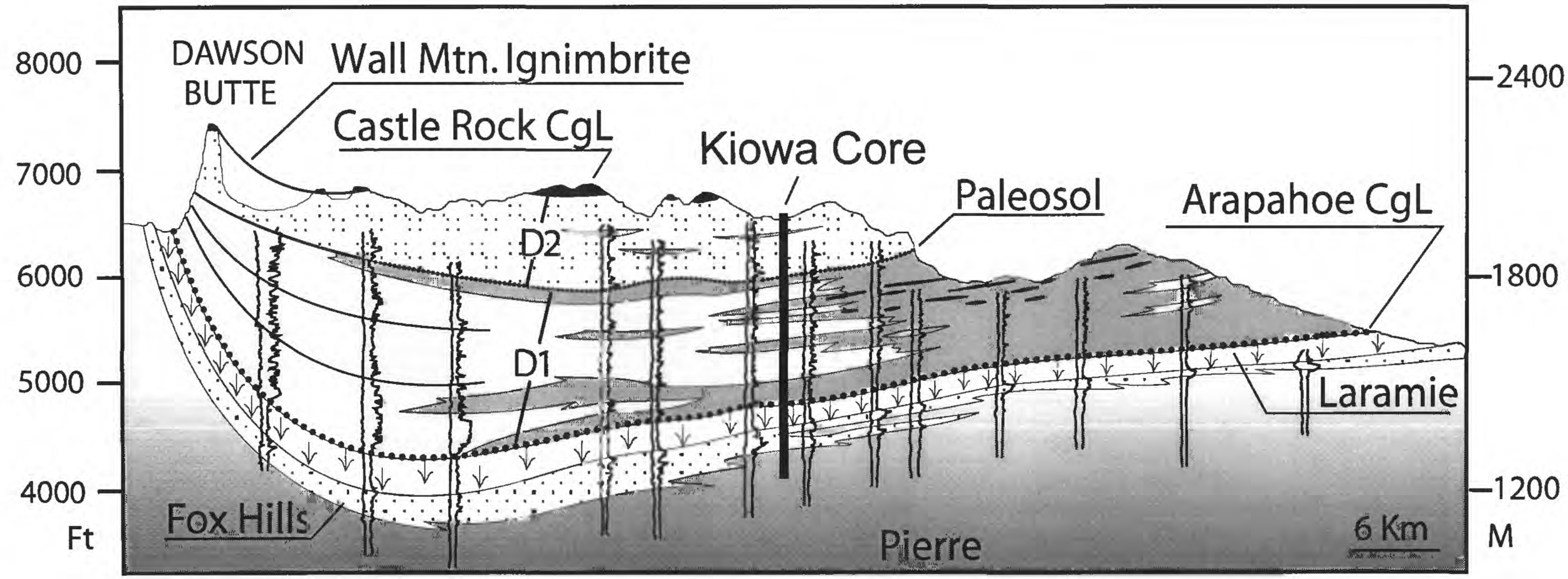

Figure 7 Generalized chart showing bedrock geology in the Denver Basin, Colorado, along cross section A-A' (location of cross section shown in figure 5)

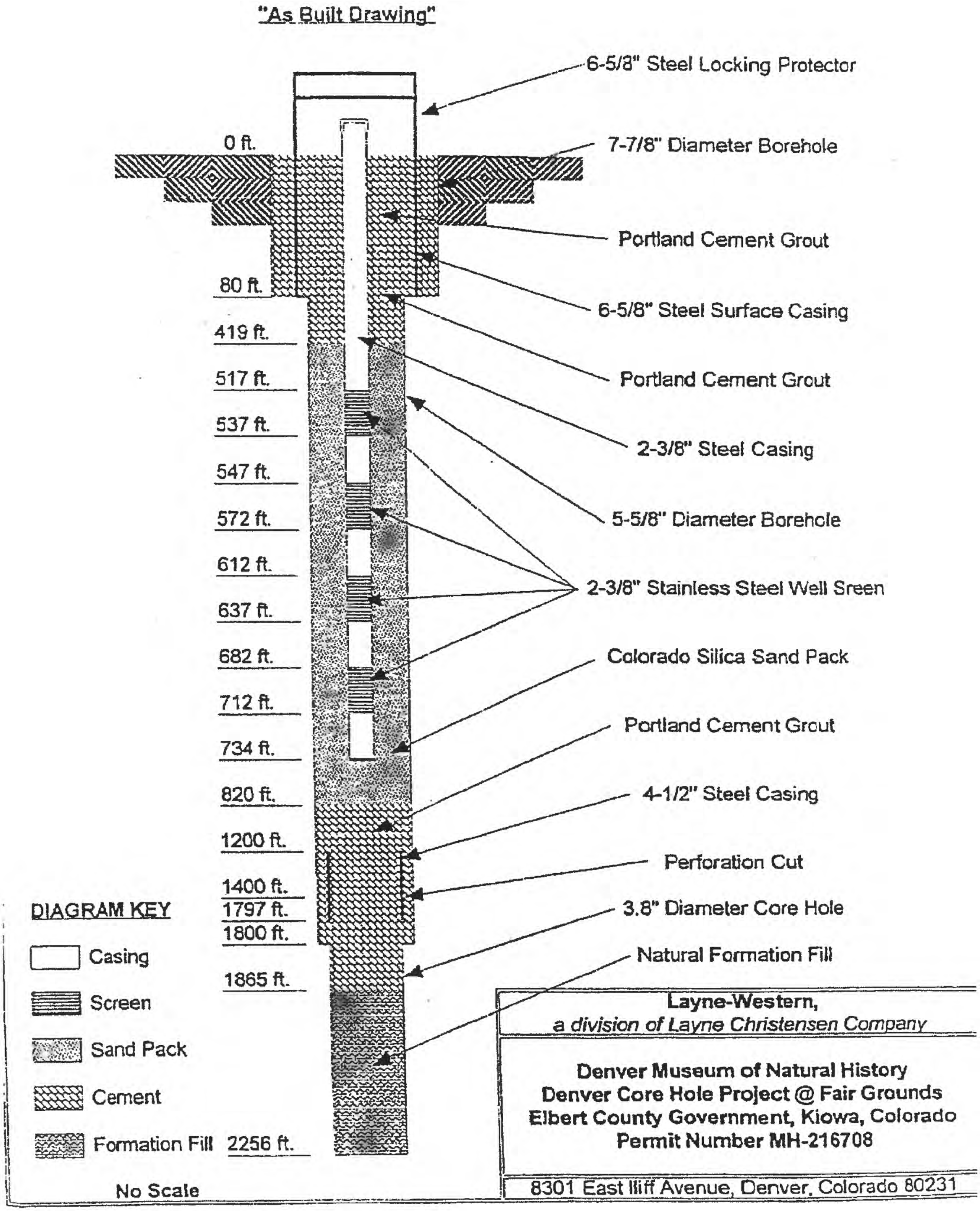

Figure 8 Well completion diagram of the Kiowa core hole

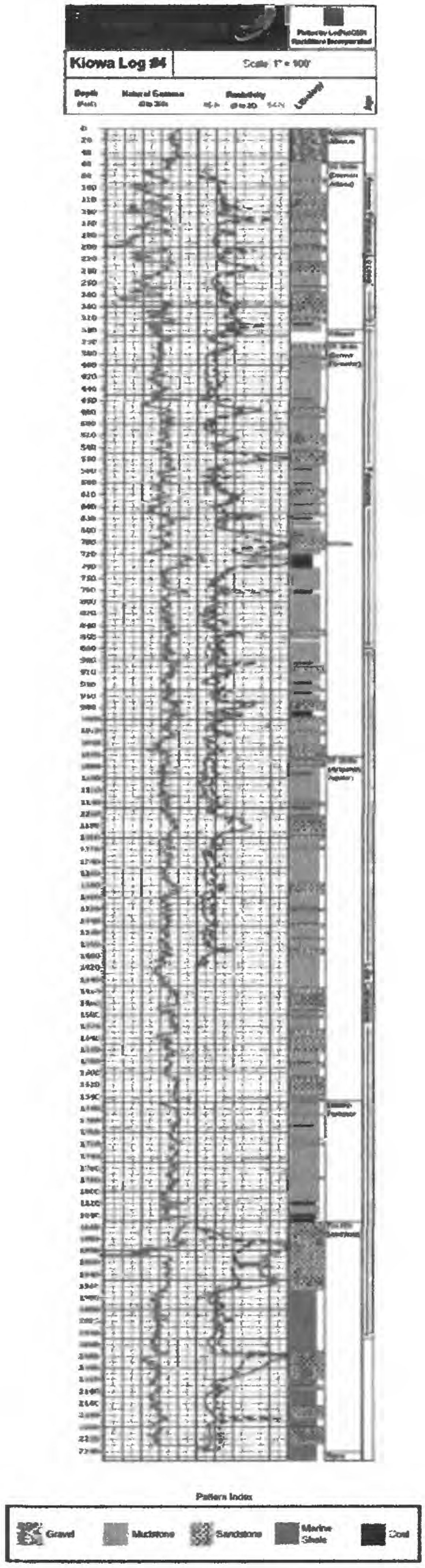

Figure 9 Graphic lithologic section of the Kiowa #1 core hole with electric log pattern shown alongside

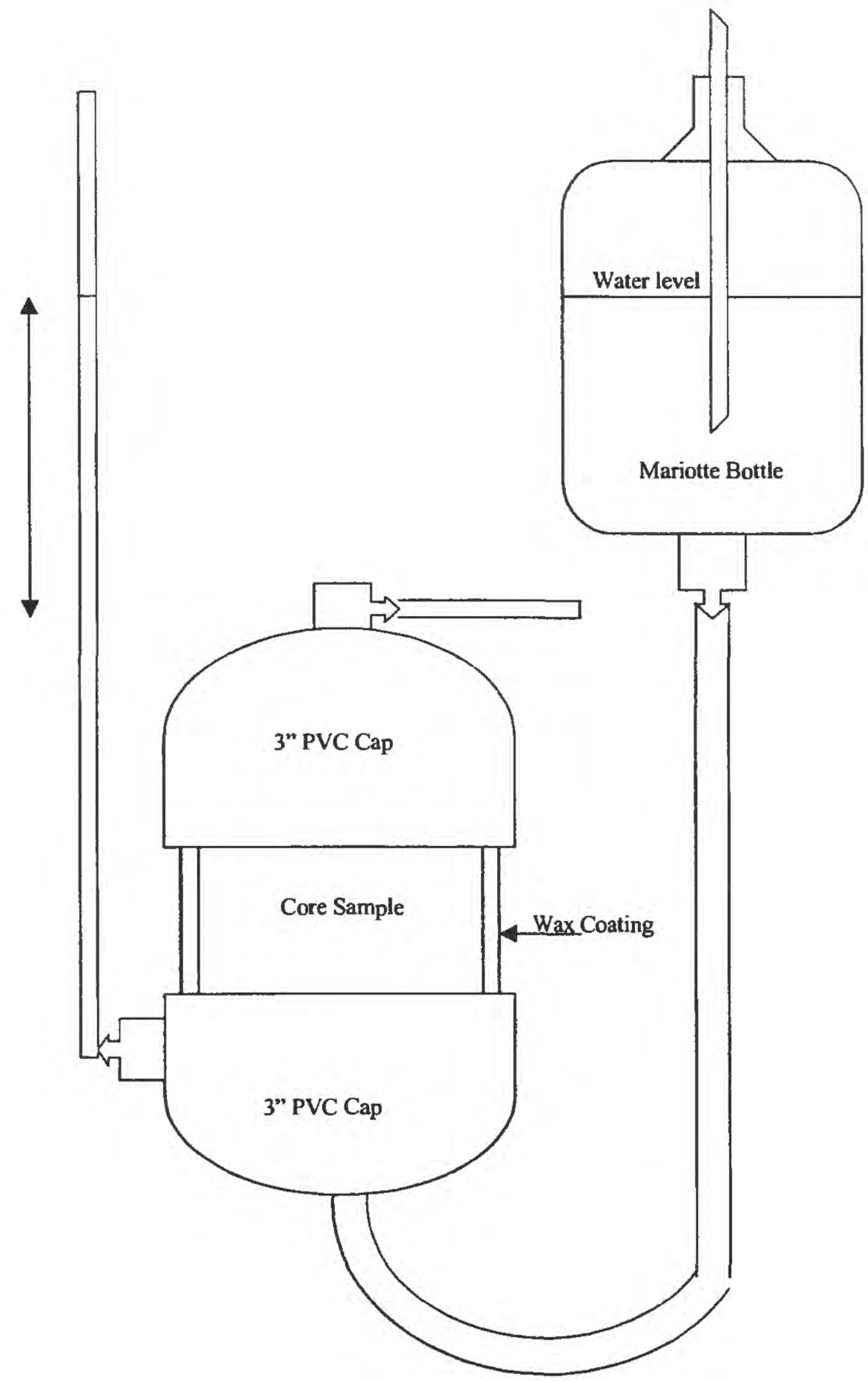

Figure 10 Schematic diagram of the constant head permeameter measurement device. Not to scale.

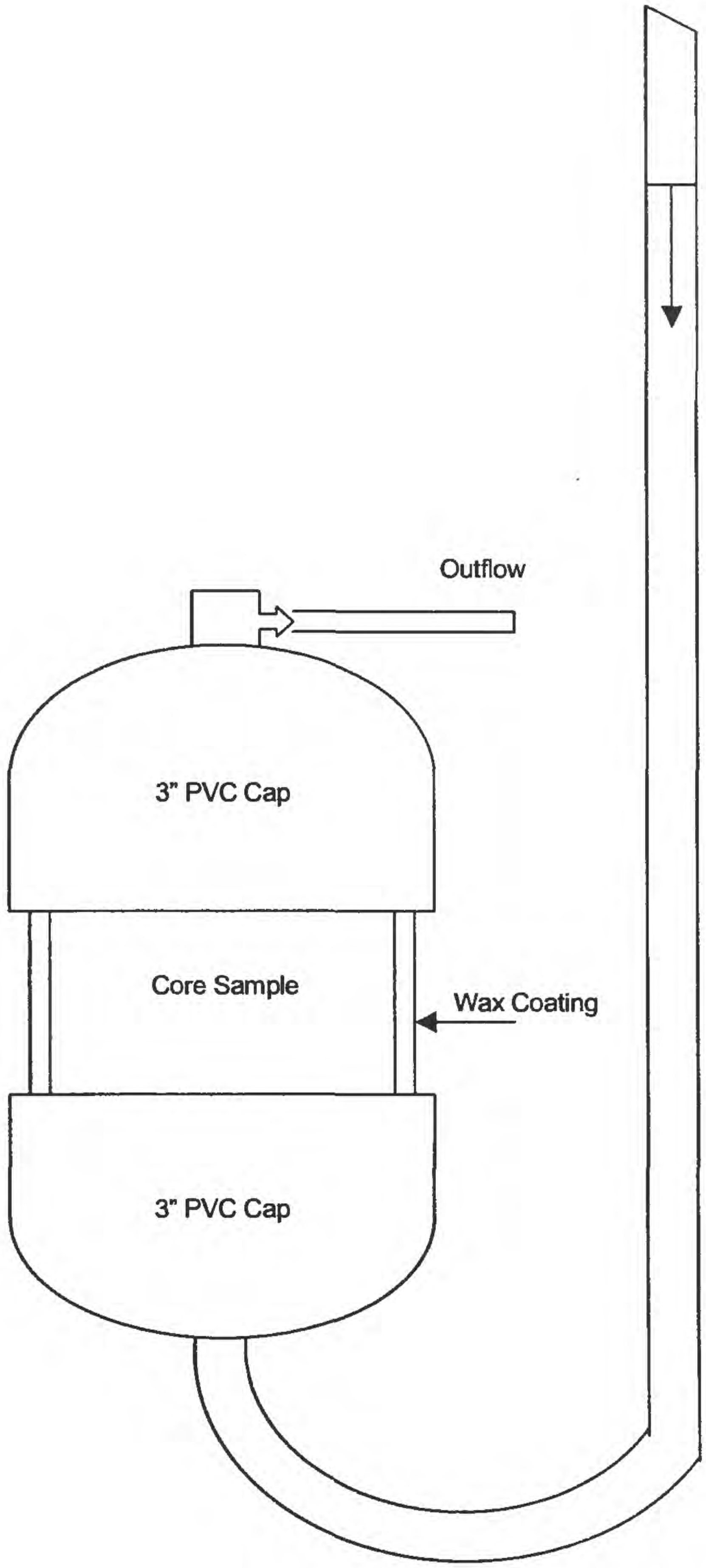

Figure 11 Schematic diagram of the falling head permeameter measurement device. Not to scale.

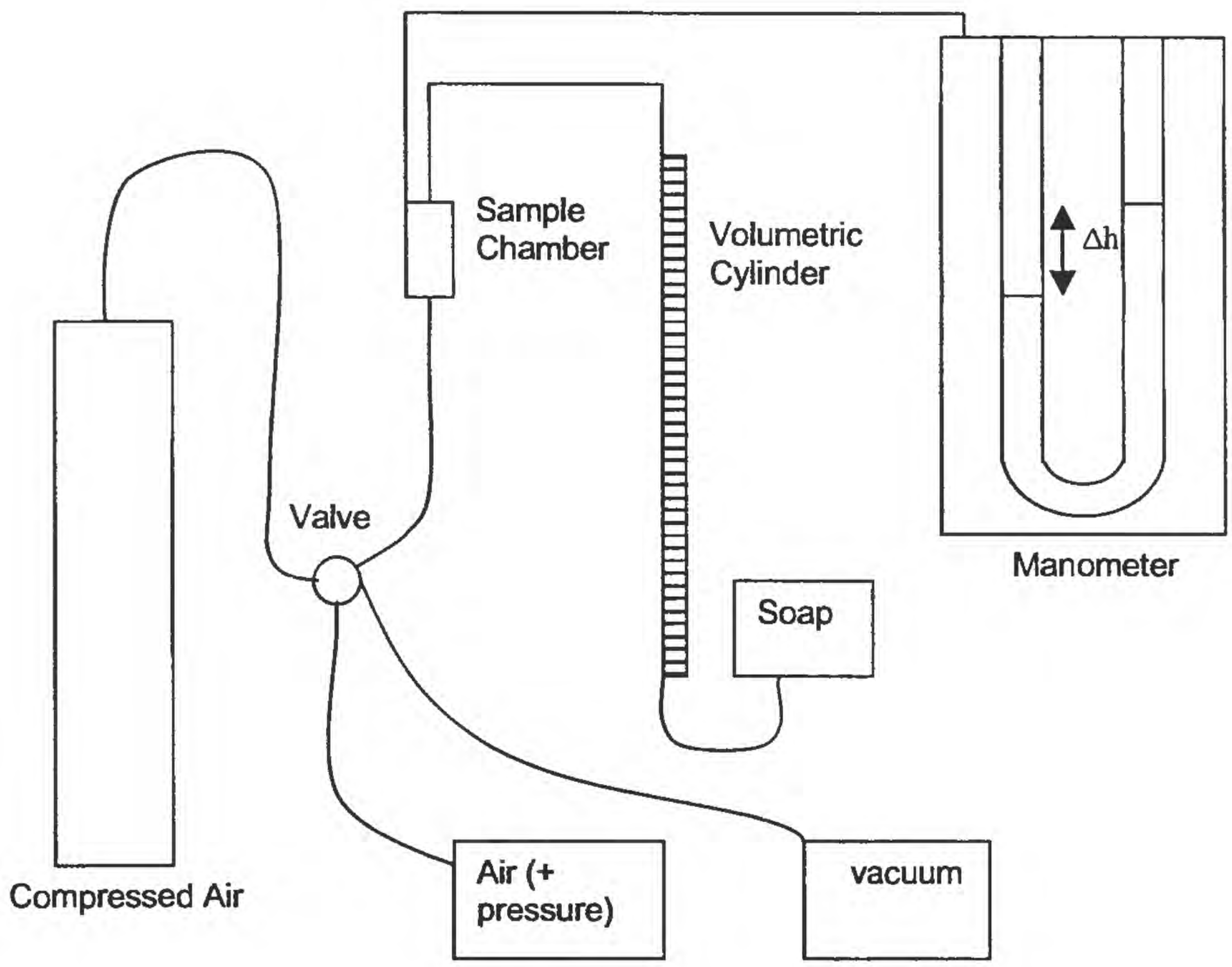

Figure 12 Schematic diagram of the air permeameter device. Not to scale.

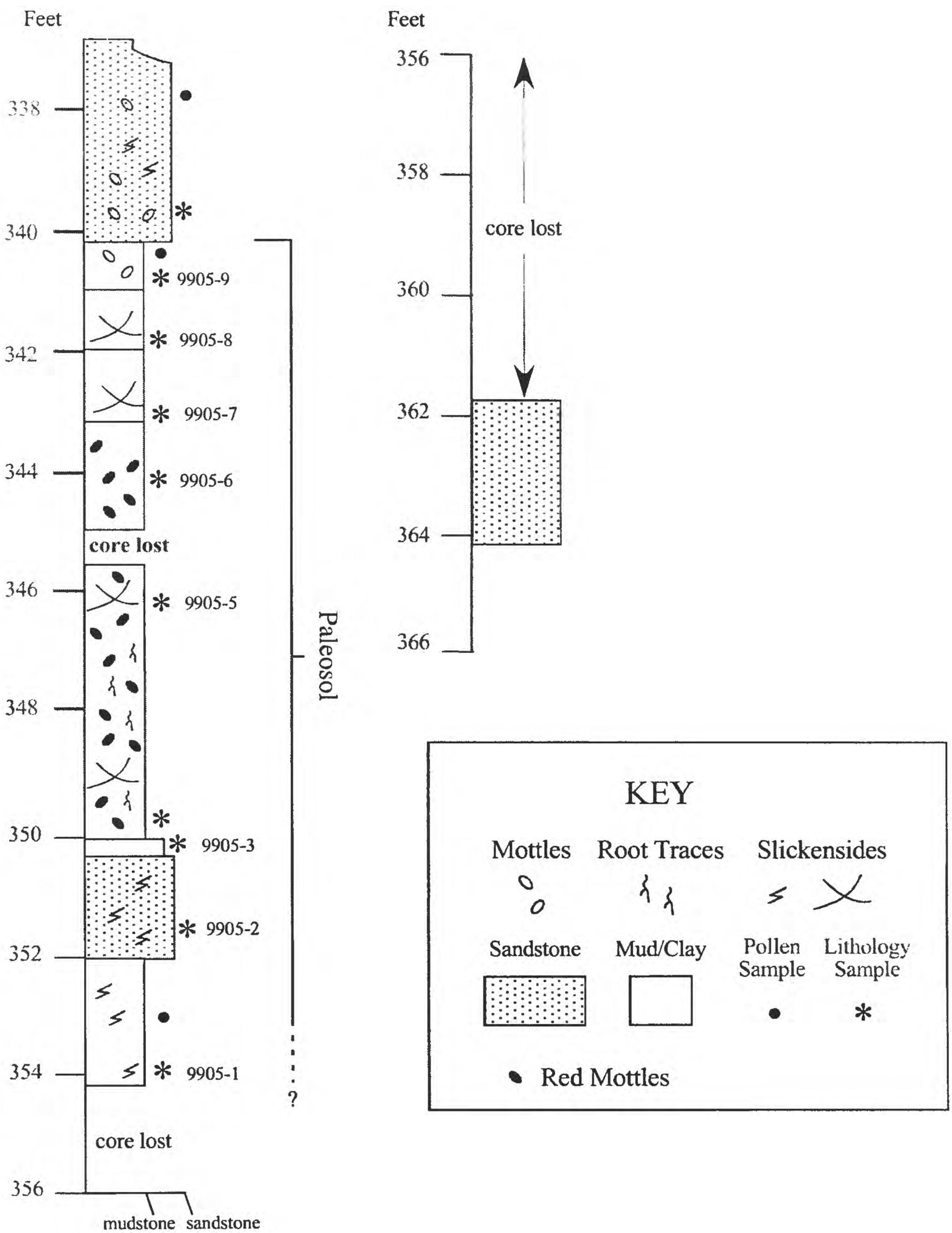

Figure 13 Schematic column showing main paleosol series in the Kiowa #1 core

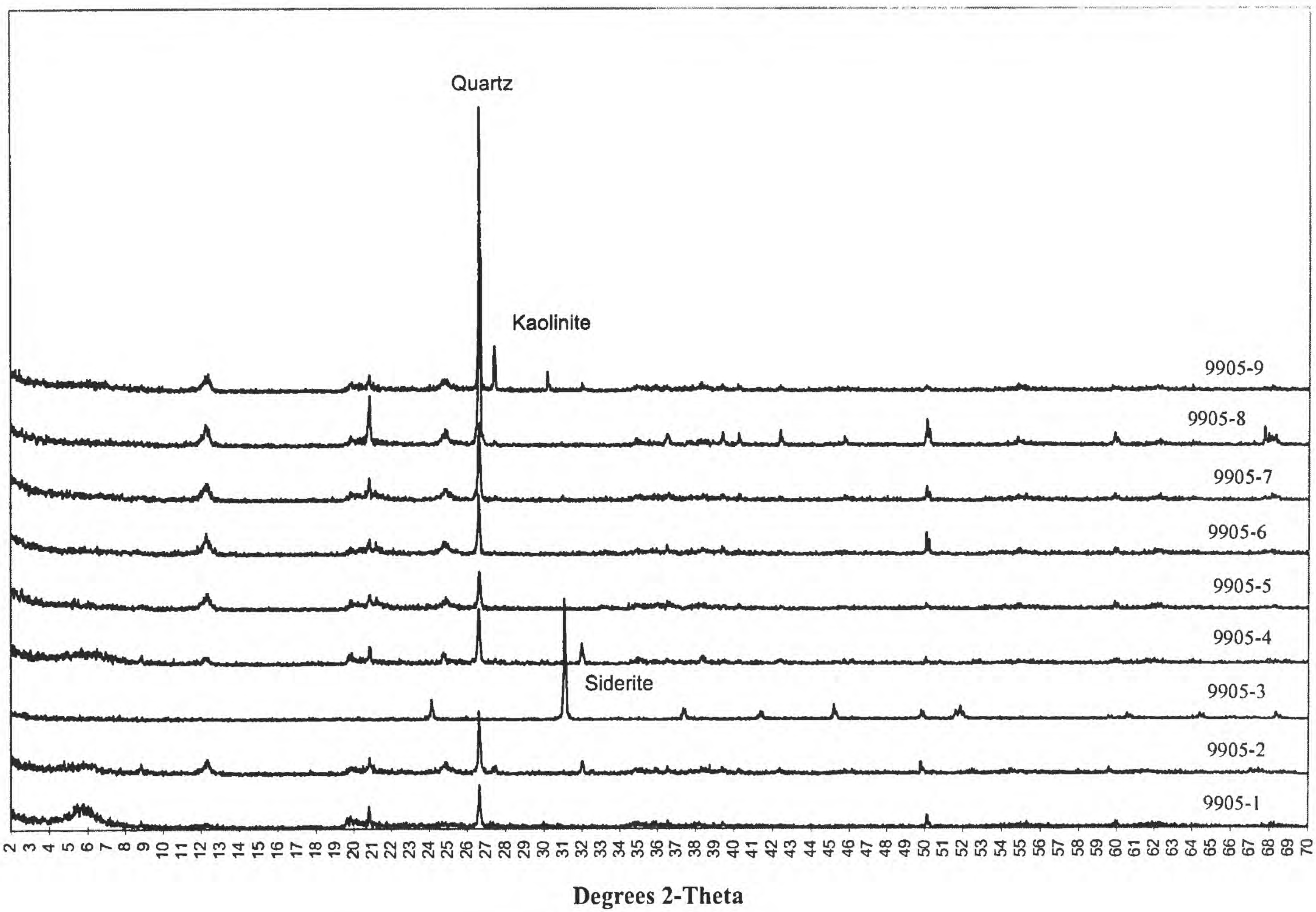

Figure 14. Paleosol Series Whole Rock XRD Patterns

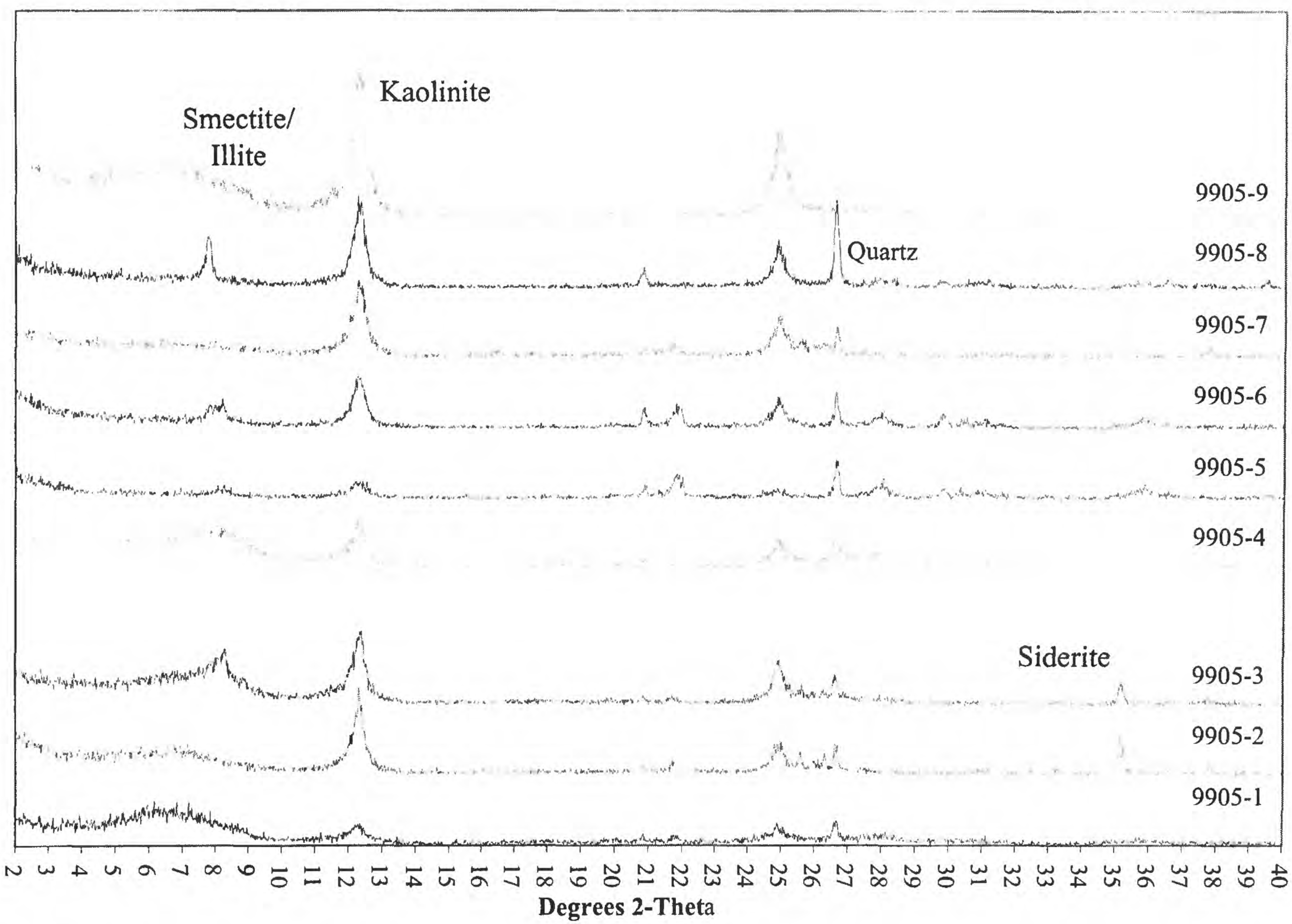

Figure 15. Clay Size (<2 micron) Diffraction Pattern

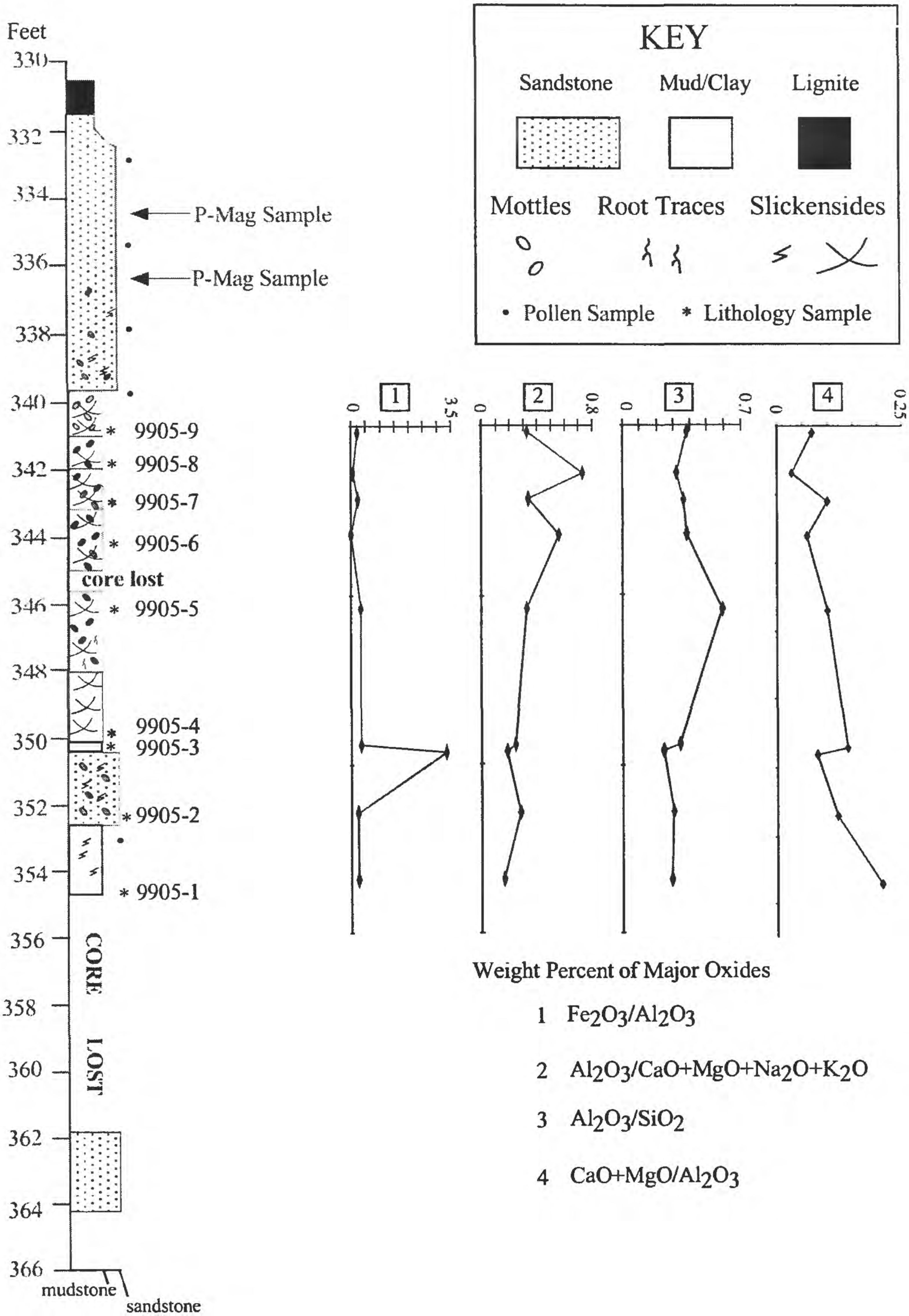

Figure 16 Whole rock x-ray fluorescence data from the paleosol series in the Kiowa #1 core

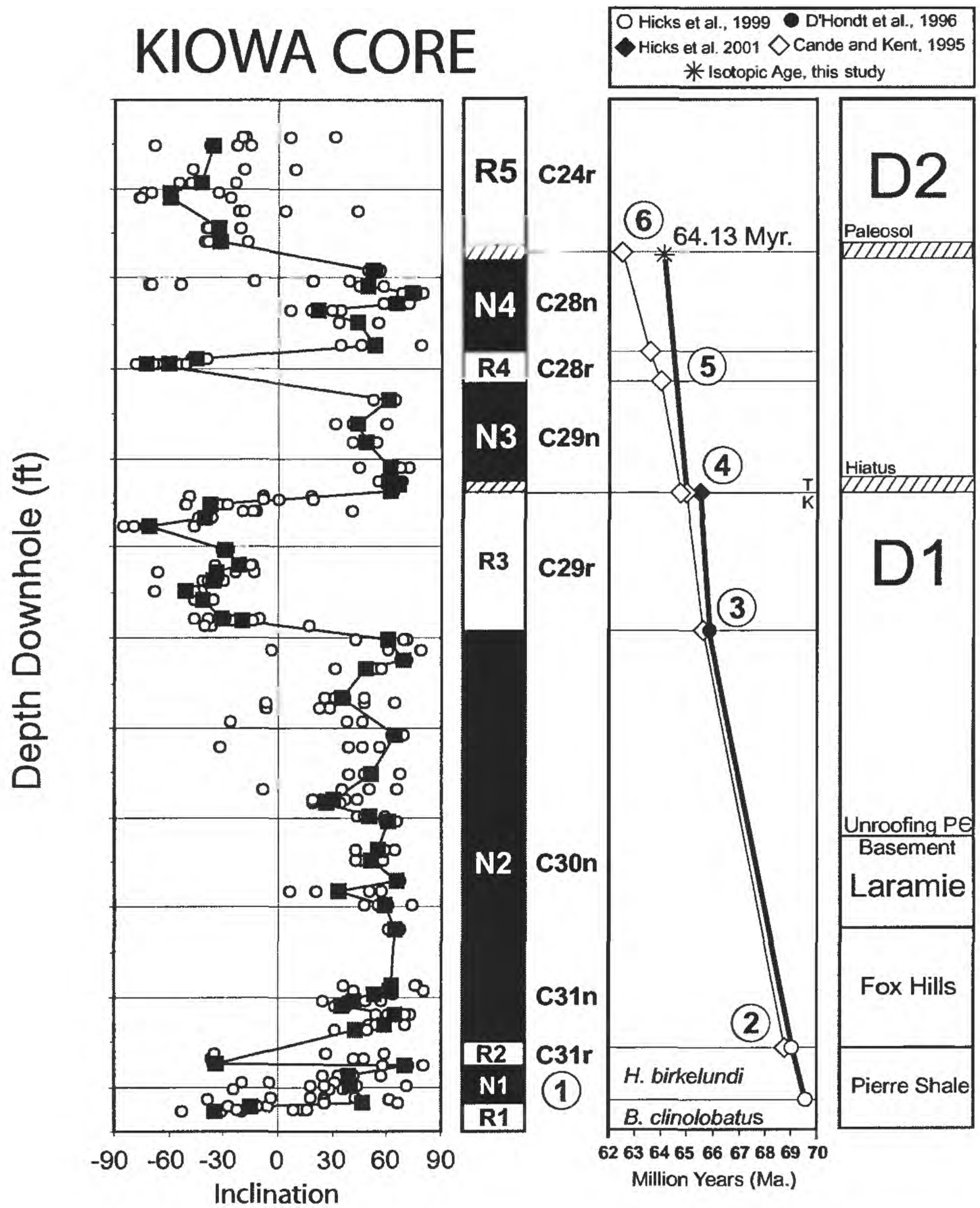

Figure 17. Plot of sample inclination vs. stratigraphic height for all the paleomagnetic samples analyzed from the Kiowa #1 core. The three to four samples processed from each level are shown as small open circles. Calculated site mean for each level is shown by a filled black square. No mean was calculated or plotted if the mean directions of the samples in the site exceeded the parameters outlined in the text. The interpreted polarity of each section is shown to the right (black/white, normal/reversed), labeled from C31r through C24r. Two age correlations are shown: thin line and open diamonds is the age correlation of Cande and Kent (1995, CK95); dashed line is the age correlation based on: isotopic ages; precessional ages of D Hondt et al. (1996); calibrations after Hicks et al. (1999, 2001). **1.** N1 is believed to be a spurious normal interval similar to that found by Hicks et al. (1999) at the same level at Red Bird, Wyoming. **2.** Age and position of top of C31r and projected top of *Baculites clinolobatus* after Hicks et al. (1999), and after CK95. **3.** Precessional age of the base of C29r after D Hondt et al. (1996) and age from CK95. **4.** 65.51 Ma age of the K/T boundary after Hicks et al. (2001), and 65.0 Ma age after CK95. Also shown is the CK95 age for the top of C29r. **5.** Age of C28r after CK95. **6.** Isotopic age of 64.13 Ma (see also Table 8) obtained from just below the level of the paleosol. Stratigraphy of the magnetostratigraphic section is shown on the right, with the level of unroofing of the Precambrian basement, the hiatus that marks the level of the K-T boundary, and the level of the paleosol disconformity.

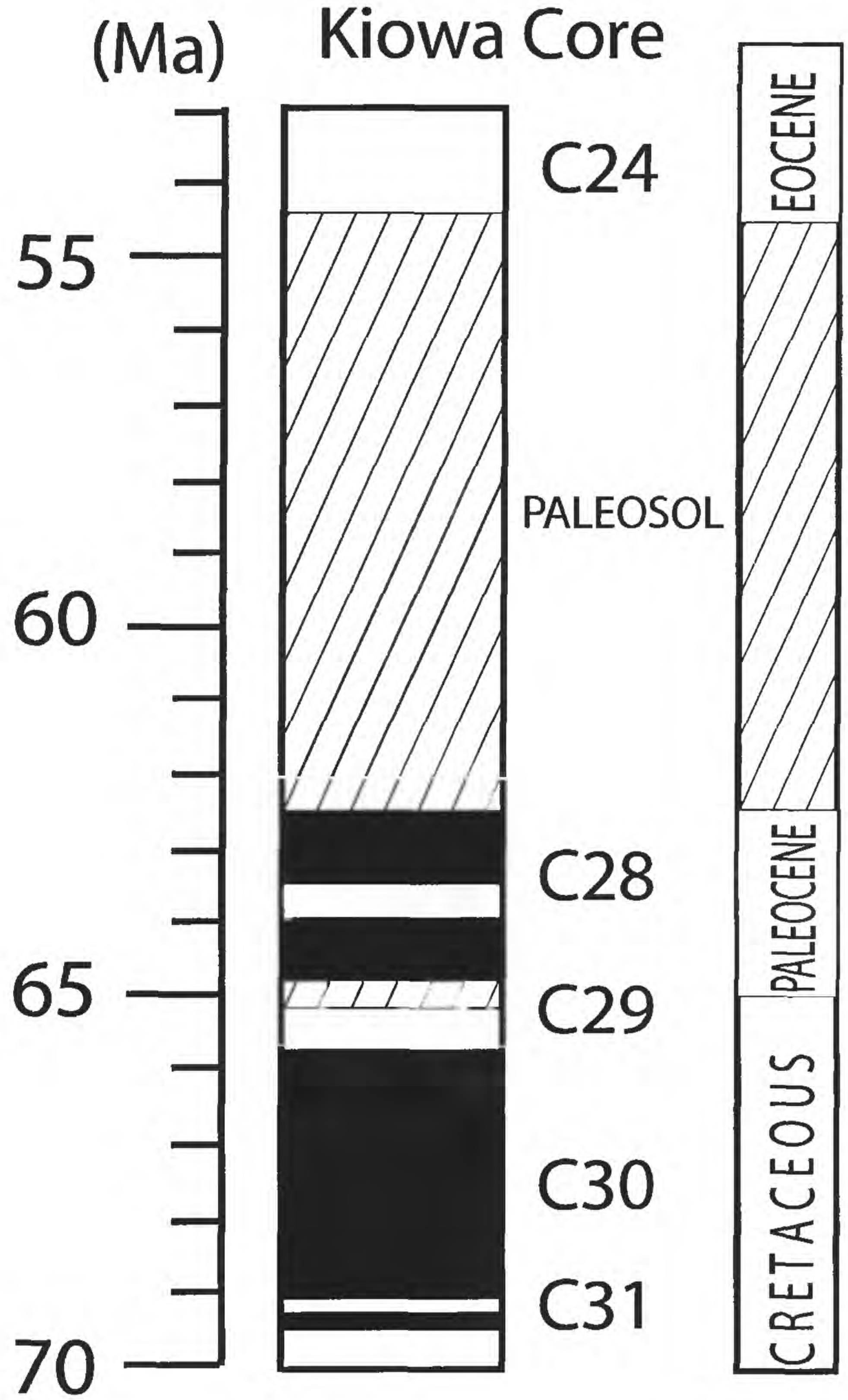

Figure 18 Age correlation diagram of the Kiowa core. Polarity normal/black, reverse/white, shaded intervals represent disconformities or hiatuses

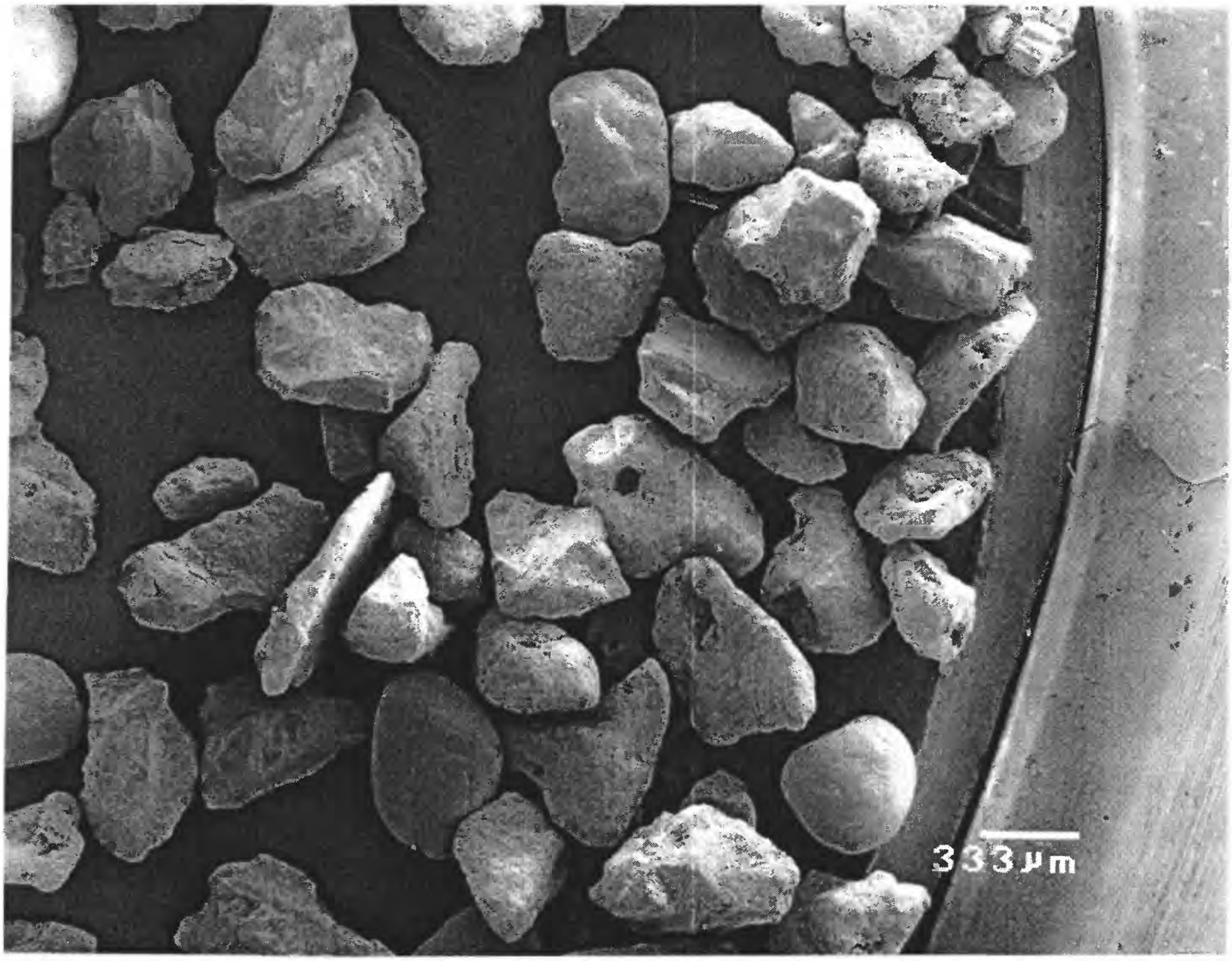

Figure 19 Scanning electron photomicrograph of selected sand grains from the Kiowa #1 core taken from a depth of 371 feet. Note that grain rounding ranges from sub-angular to well-rounded, suggesting multiple sources

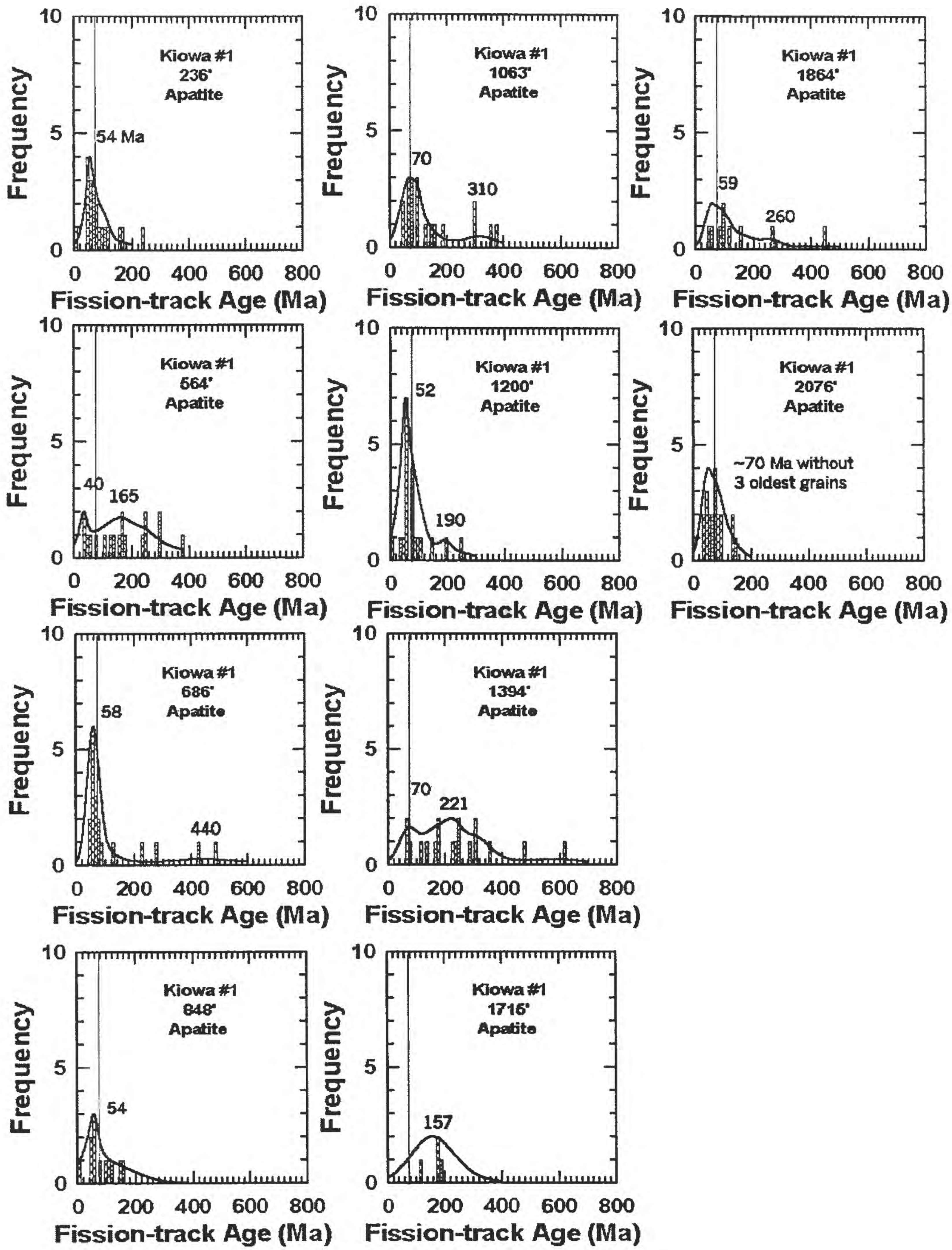

Figure 20a Apatite fission track data from the Kiowa #1 core

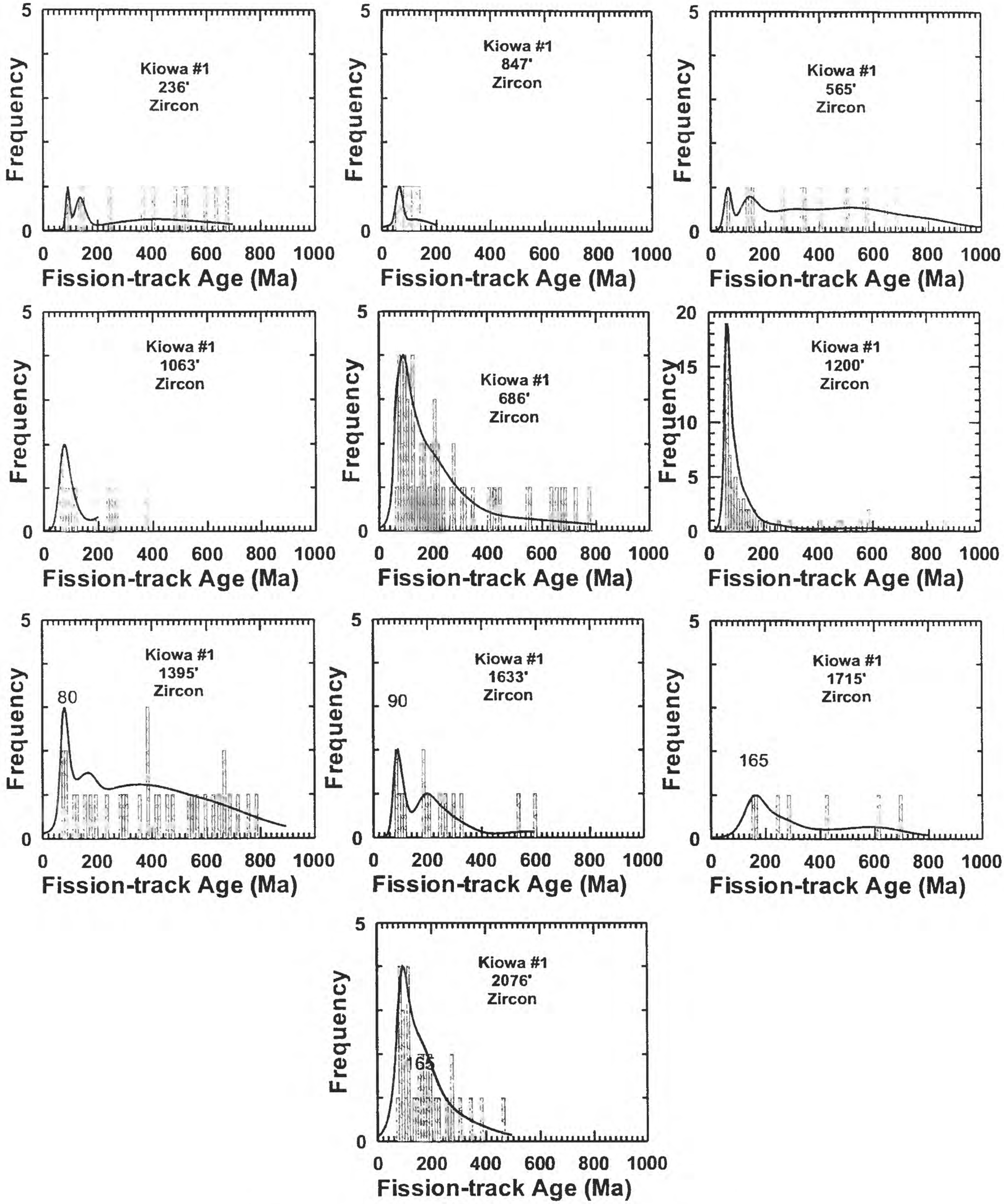

Figure 20b Zircon fission track data from the Kiowa #1 core

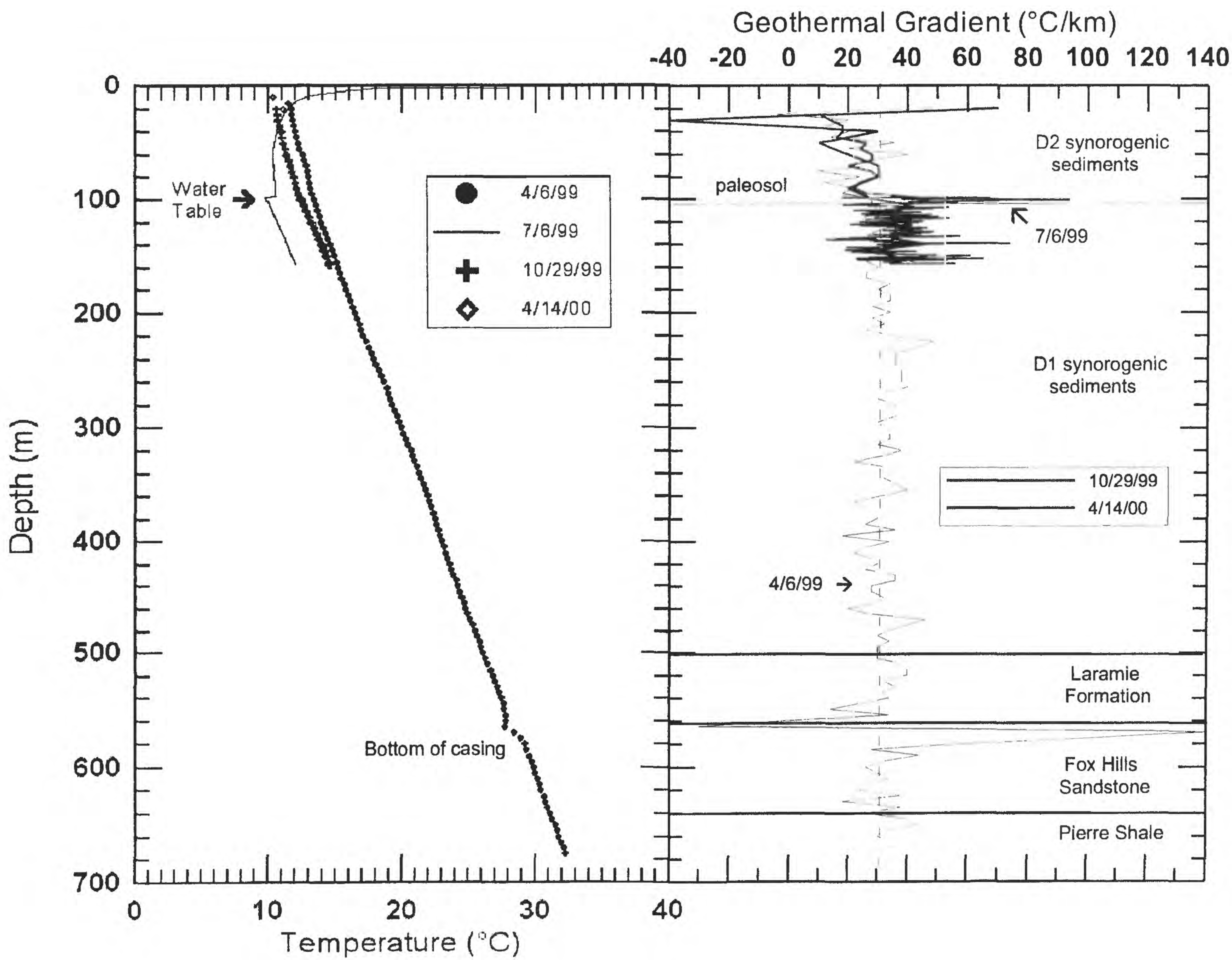

Figure 21 Temperature and gradient plots for the Kiowa #1 core

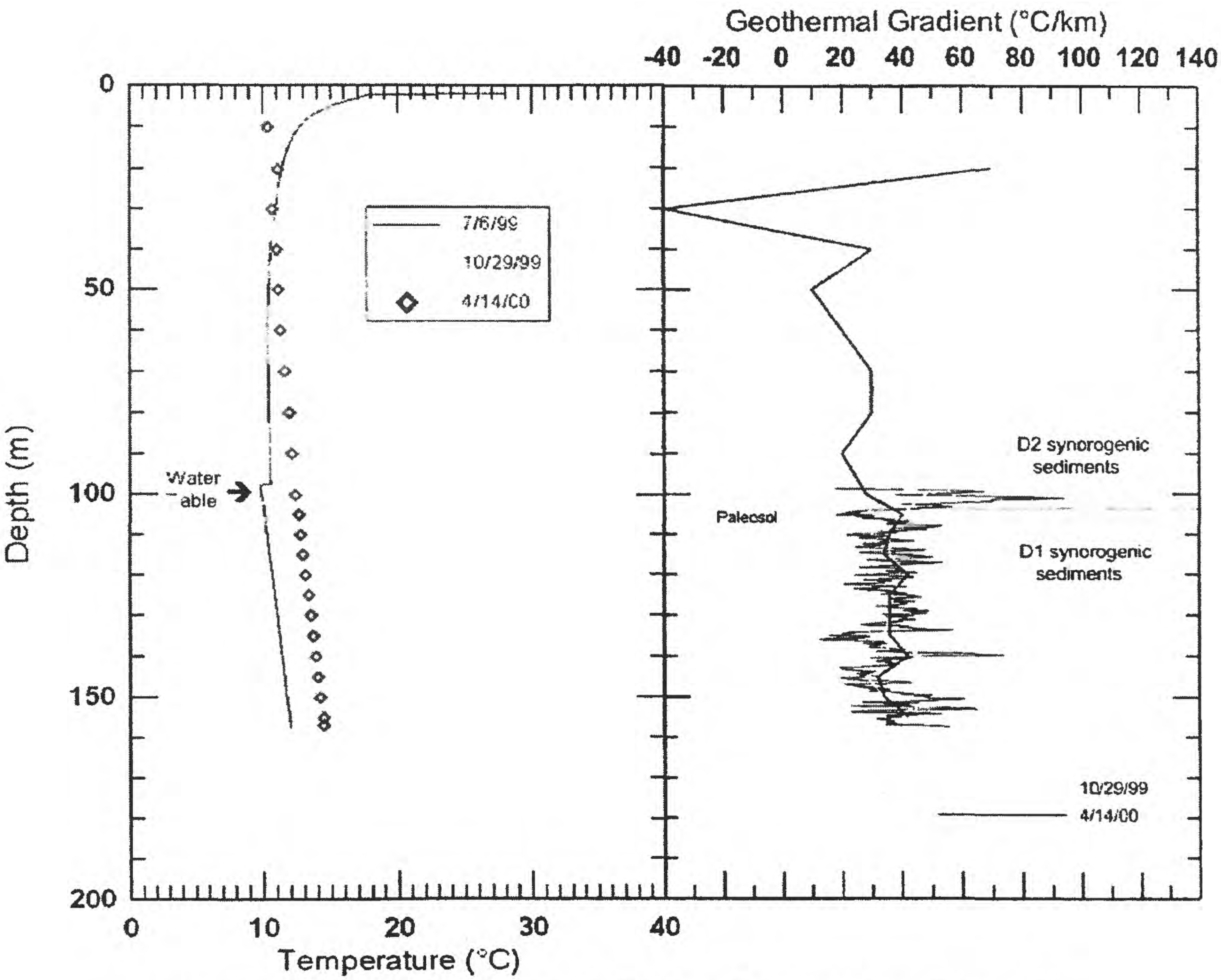

Figure 22. Temperature and gradient plots for shallow portion of Kiowa #1.

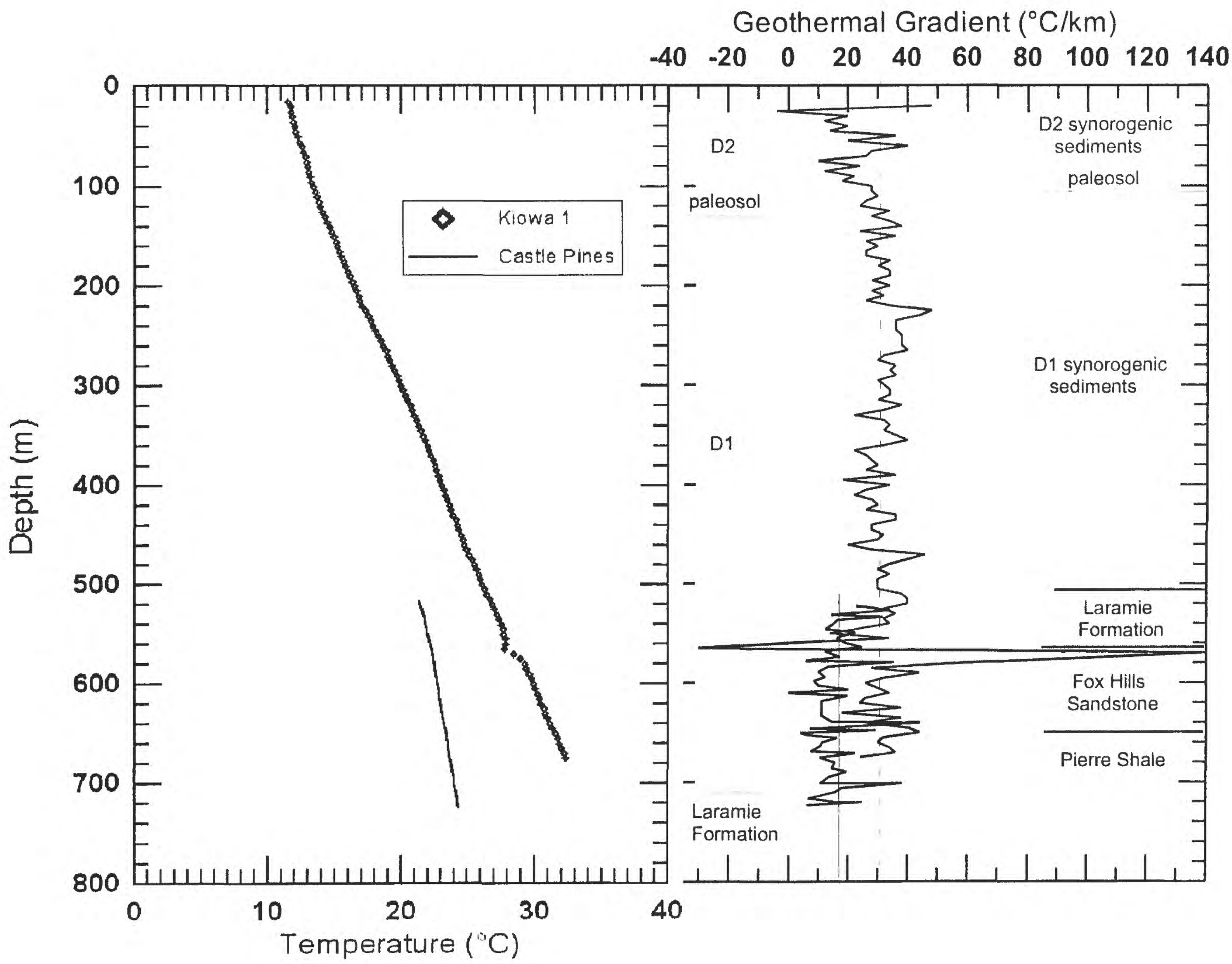

Figure 23 Comparison of temperature and gradient plots for Kiowa #1 and Castle Pines wells, Denver Basin, Colorado

Table 1. Ash content, sulfur content and forms, and sulfur isotopic composition of coaly samples and shales of the lower Laramie Formation, Kiowa core.

Depth (ft)	Description	Ash (wt.%)	S total (wt.%)	SO_4 S	Pyrite S	Organic S	^{34}S per mil
1688.5	Shale w. organics	51.3	0.43	-	-	-	+3.0
1689.5	Gray shale	77.0	0.09	-	-	-	+3.5
1729.5	Gray shale	75.9	0.08	-	-	-	-3.3
1816.5	Shale w. organics	70.8	0.09	0.01	0.02	0.02	-0.6
1817.5	Coaly layer	4.9	0.60	0.02	0.01	0.01	-0.9
1818.0	Coaly layer	8.4	0.45	0.02	0.02	0.02	+1.4
1820.0	Coaly layer	14.4	0.50	0.02	0.02	0.02	+0.3
1821.0	Coaly layer	27.1	0.51	0.02	0.02	0.02	0.0
1836.5	Gray shale	85.4	0.02	-	-	-	-0.2
1839.0	Shale w. organics	65.3	0.26	0.03	0.13	0.10	-2.2
1840.0	Coaly layer	20.3	0.61	0.01	0.04	0.56	+0.3
1841.0	Coaly layer	7.38	0.46	0.05	0.02	0.39	+1.3
1848.0	Gray shale	79.2	0.12	0.01	0.05	0.06	-3.9
1849.0	Coaly layer	31.0	0.20	0.02	0.07	0.11	+3.6
1850.0	Coaly layer	8.0	0.23	0.03	0.05	0.15	+5.1

Table 2. Lithologic descriptions of the Kiowa Core. Units are feet.

Start	End	Thickness	Description	Tube
0	1.1	1.1	sand, pale brown, quartz and feldspar granules, modern roots,	box
1.1	1.7	0.6	soil, dark organic rich clay in sandy matrix, coarse grained	box
1.7	1.8	0.1	sand, pale brown, unconsolidated	box
1.8	2.2	0.4	mudstone, dark brown organic rich soil horizon	box
2.2	2.3	0.1	sand, pale brown, quartz and feldspar granules, modern roots, unconsolidated	box
2.3	2.6	0.3	modern soil, dark brown organic rich soil horizon	box
2.6	5.0	2.4	sand, silty, unconsolidated	box
5	7.0	2.0	sand, light brown, very coarse, quartz granules, subrounded to sub-angular, unconsolidated	box
7	7.6	0.6	sand, poorly sorted	box
7.6	10.0	2.4	sand	box
10	10.7	0.7	mudstone, light brown, very fine, argillaceous, micaceous, well consolidated	box
10.7	11.0	0.3	sandstone, light brown, fine, micaceous, subrounded, fairly well consolidated	box
11	11.8	1.0	mudstone, light brown, argillaceous, micaceous	box
11.8	13.1	1.2	sand, light brown, medium grains, subangular, moderately well sorted, some clasts	box
13.1	13.3	0.2	sand, light brown, medium to coarse grains, same as above	box
13.3	15.0	1.7	sand, light brown, coarse to granular, fining upwards, subrounded, massive bedding with poor consolidation	box
15	20.0	5.0	sand/gravel, very coarse, chert, feldspar and quartz fragments, rounded to subangular, poorly sorted	box
20	21.3	1.3	sand, light brown, very coarse, coarsening upwards, quartz, subrounded, poorly consolidated	box
21.3-	22.0	0.7	sand, brown, coarse-medium grained, poorly consolidated	box
22-	22.7	0.7	core lost	box
22.7-	23.9	1.2	sand, light brown, very coarse, coarsening upwards, quartz	box
23.9	24.2	0.3	sand, light brown, medium-fine grained, slightly argillaceous	box
24.2	25.0	0.8	sand, medium-coarse grained, quartz	box
25	25.2	0.2	core lost	box
25.2	26.6	1.4	sand, quartz and feldspar granules and pebbles, subangular to rounded, moderately sorted	box
26.6	27.1	0.5	sand, medium grained, feldspars, well sorted, sharp contact	box
27.1	27.7	0.6	core lost	box
27.7	28.7	1.0	sand, medium-fine grained, fining upwards, quartz and feldspars	box
28.7	28.9	0.2	sand, fine, argillaceous, sharp contact between medium-fine sands and clay- rich fine sand beds	box

28.9	30.0	1.1	sand, medium-coarse grained, quartz and feldspars, red weathering zones (1.5 mm in width)	box	
30	30.2	0.2	core lost	box	
30.2	31.3	1.1	sand, light brown, medium-coarse grained, occasional quartz grains with small feldspars	box	
31.3	32.5	1.2	sand, light brown, very coarse, occasional quartz pebbles and small feldspars, subangular	box	
32.5	32.7	0.2	core lost	box	
32.7	34.6	1.9	sand, light brown, very coarse, quartz pebbles and small feldspars, subangular	box	
34.6	37.5	2.9	core lost	box	
37.5	40.0	2.5	sand/gravel, very coarse, quartz and granite granules, angular, poorly sorted	box	
40	42.5	2.5	core lost	box	
42.5	45.0	2.5	gravel, very coarse grained, pebbles, arkosic, contains quartz, angular and subrounded, poorly sorted	box	
45	54.3	9.3	core lost	box	
54.3	54.9	0.6	mudstone, yellowish-brown, very fine, argillaceous, quartz cobble (100mm)	box	
54.9	56.1	1.2	sand, brown, coarse-very coarse grained, mottled reddish-orange	box	
56.1	57.4	1.3	sand, coarse, quartz and feldspar granules, massively bedded, mottled reddish-yellow	box	
57.4	57.7	0.3	silty mudstone ,olive green, argillaceous	box	
57.7	69.8	12.1	silty mudstone, blue-green, argillaceous, reddish-orange mottles, sharp contact	box	
69.8	70.0	0.2	core lost	box	
70	73.3	3.3	silty mudstone, grayish-green 10GY5/2, mottled		1
73.3	75.0	1.7	core lost		
75	80.0	5.0	silty mudstone, grayish-green 10GY5/2		2
80	81.0	1.0	drilling mud		3
81	89.0	8.0	muddy sandstone, grayish-green 10GY5/2, fines upward from coarse base		
89	92.8	3.8	muddy sandstone, grayish-green 10GY5/2, fining up, feldspar granules to pebble size, poorly sorted		4-5
92.8	107.0	14.2	silty mudstone, grayish-green 10GY4/2 to grayish blue green 5BG 5/2 with slickensides at 103.2, mottled, iron stains		6-8
107	108.0	1.0	muddy sandstone, medium-fine grained, 5GY 5/2, fining upwards, with pale mottles		
108	111.0	3.0	muddy sandstone, dusky yellow green 5GY 5/2 to 10GY 5/2, fining upwards to silty mudstone, feldspars, micaceous		9
111	124.2	13.2	sandstone, grayish green 5G 5/2, moderately well-sorted, fining up, coarse base fining up to laminated sandy mudstone		10

124.2	135.4	11.2	sandy mudstone, dusky blue green 5 BG 3/2 to 5G 5/2, arkosic, well sorted, fining up to a muddy sandstone with thin layers of black organic matter, bioturbated	12-14
135.4	137.9	2.5	silty mudstone, grayish green 5G 5/2, fining upwards, well sorted	14
137.9	141.0	3.1	sandstone, fine-medium grained, dark greenish gray 5G 4/1, well sorted, micaceous, flaser cross-beds, fining up to muddy sandstone grayish blue green 5BG 5/2,	14-15
141	143.2	2.2	mudstone, dark gray N3, sand rich at bottom, bioturbated	
143.2	144.0	0.8	mudstone, dark greenish gray, 5GY 4/1-5G 4/1	
144	145.2	1.2	sandstone, medium grained, cross-bedded, fining upwards, organic drape, jarosite staining	16
145.2	157.3	12.1	sandstone, dark greenish gray, 5GY 4/1, poorly sorted, coarse base fining upwards to medium grained, trough crossbeds at 148'	17-18
157.3	158.5	1.2	sandy mudstone, dark greenish gray, 5GY 4/1, sharp contact	
158.5	162.6	4.1	core lost	
162.6	170.5	7.9	silty mudstone, grayish blue green 5BG 5/2, with dark yellowish orange 10YR 6/6 mottles and roots	19-20
170.5	179.2	8.7	sandstone, fining upwards coarse - fine grained, medium bluish gray 5B 7/1, arkosic, moderately well-sorted, fine laminations	22
179.2	188.2	9.0	silty mudstone, grayish green 10G 4/2, common slickensides, moderate olive brown 5y 4/4 mottles below 185.3	23
188.2	192.0	3.8	silty mudstone, dusky yellow-green to grayish olive green 5GY 4/2 with orange mottles	24-25
192	193.2	1.2	sandy mudstone, olive green 5GY 4/2, floating sand grains	26
193.2	197.6	4.4	silty mudstone, grayish green 10G 4/2, abundant slickensides, orange-brown mottles between 194.5 and 196.3	
197.6	199.2	1.6	muddy sandstone, coarse -grained, fining upward to silty mudstone, greenish gray 5G 6/1, moderately well sorted	27
199.2	202.3	3.1	muddy sandstone, coarse -grained, fining upward to fine-grained, greenish gray, 5GY 4/1, arkosic	28
202.3	207.5	5.2	sandstone, coarse to very coarse, poorly sorted, rounded to subrounded, core barrel was dropped	
207.5	212.5	5.0	silty mudstone, dusky yellow green 5GY 5/2, iron stains and mottles of moderate olive brown 5Y 4/4	29
212.5	213.4	0.9	silty mudstone dusky blue green 5BG 3/2, slickensides	30
213.4	214.4	1.0	sandstone, fine-grained, dusky yellow green 5GY 5/2, fairly well-sorted, angular, fining upwards	
214.4	215.5	1.1	core lost	
215.5	217.1	1.6	sandy mudstone, dusky yellow green 5GY 5/2, quartz rich	31
217.1	220.5	3.4	silty mudstone, orange mottles, slickensides	
220.5	222.5	2.0	silty mudstone, pale olive 10y 6/2 - grayish olive 10y 4/2 bedding	32
222.5	225.5	3.0	core lost	
225.8	232.0	6.2	sandstone, medium grained greenish gray 5G 6/1, fining upward, massive, arkosic, poorly sorted, feldspar altered to kaolinite, some potassium feldspar	33

232	233.5	1.5	sandstone, coarse grained 5G 6/1arkosic sand, fines upward	
233.5	240.0	6.5	sandstone, coarse - medium grained medium bluish gray 5B 5/1, fining up, arkosic, fairly well sorted, sub-angular - rounded	34-35
240	245.9	5.9	sandstone, dark greenish gray 5G 4/1, very coarse, arkosic, quartz, mod well-sorted, pebbles with intraclasts, orange stains	36
245.9	247.9	2.0	core lost	37
247.9	248.2	0.3	muddy sandstone, dusky yellow-green 5GY 5/2, fine grained	
248.2	248.4	0.2	sandy mudstone, grayish-green 10G 4/2, micaceous	
248.4	249.2	0.8	muddy sandstone, dusky yellow-green 5GY 5/2, fine grained, slickensides	
249.2	249.3	0.1	silty mudstone, olive gray 5Y 4/1, sharp contact	
249.3	252.2	2.9	sandy mudstone, olive gray 5Y 4/1, micaceous	
252.2	253.4	1.2	silty/sandy mudstone, greenish-gray 5G 6/1, intercalated layers of silty mudstone and sandy mudstone, moderately well sorted	38
253.4	259.3	5.9	silty mudstone, greenish-gray 5G 6/1, fining upwards sequence, micaceous, moderately/ well sorted, slickensides and mottles	39
259.3	260.5	1.2	sandy mudstone, dusky yellow green 5GY 5/2, fine grained	
260.5	263.4	2.9	sandy mudstone, dark greenish gray 5GY 4/1, micaceous	40
263.4	263.6	0.2	silty mudstone, greenish black 5GY 2/1	
263.6	265.5	1.9	sandy mudstone, dark greenish-gray 5GY 4/1, micaceous, red and orange mottles, slickensides	
265.5	267.5	2.0	muddy sandstone, dusky yellow green 5GY 5/2, fine grained arkosic sands, slickensides	41
267.5	269.7	2.2	sandstone, coarse grained, fining upwards, arkosic	
269.7	269.9	0.2	silty mudstone, sharp contact	
269.9	272.2	2.3	core lost	
272.2	276.2	4.0	silty mudstone, grayish green 5G 5/2, micaceous, slickensides, yellow brown mottling, root traces with neoferrans	42
276.2	277.2	1.0	muddy sandstone, grayish green 5G 5/2, micaceous	
277.2	278.1	0.9	sandstone, grayish-green 5G 5/2, very coarse, arkosic, subangular to subrounded	43
278.1	284.1	6.0	core lost	
284.1	288.1	4.0	muddy sandstone, medium dark gray N4, very fine grained with clay matrix, mottles and burrows throughout	44
288.1	289.0	0.9	silty mudstone, micaceous	45
289	289.1	0.1	mudstone, rich in silts, some clays	
289.1	289.8	0.7	sandstone, light gray N7- medium light gray N6, fine grained, bedded	
289.8	289.9	0.1	sandstone, fine grained, clay matrix	
289.9	290.9	1.0	sandstone, fine grained, micaceous with silty bedding	
290.9	291.7	0.8	sandstone, interbedded fine grained sandstone and micaceous	
291.7	292.3	0.6	sandstone, medium grained, sharp contact	
292.3	293.2	0.9	sandstone, dark gray N3 quartz rich medium sandstone, black nodule with pyrite flecks, quartz and k-spars	

293.2	293.5	0.3	sandstone, very coarse, unconsolidated, quartz and feldspar, angular, moderately will sorted	46
293.5	294.5	1.0	core lost	
294.5	295.8	1.3	sandstone, coarse grained sand fining up to medium grained, angular, poorly sorted	
295.8	298.5	2.7	sandstone, coarse sandstone fining up with abundant quartz and feldspars, angular and poorly sorted grains	
298.5	301.7	3.2	sandstone, lt. gray N8 very coarse, arkosic	47
301.7	305.0	3.3	core lost	
305	306.0	1.0	sandstone, very coarse, some large clasts (5-7mm), quartz and feldspar grains, small organic seams (5-10mm)	48
306	307.0	1.0	core lost	
307	307.5	0.5	silty mudstone, medium dark gray N4, micaceous	49
307.5	308.9	1.4	muddy sandstone, contains quartz and feldspar granules and pebbles	
308.9	309.1	0.2	silty mudstone	
309.1	312.7	3.6	sandstone, medium gray N5, medium grained, quartz, feldspar and pyrite, occasional organic layer, fining upwards	49-50
312.7	313.0	0.3	silty mudstone, medium dark gray N4	
313	313.7	0.7	sandstone , interbeds with large nodules (up to 8 cm)	
313.7	314.6	0.9	silty mudstone, medium dark gray N4, organic lenses, horizontal roots (3mm in diameter)	
314.6	315.0	0.4	sandstone, medium gray N5, medium grained, subangular, quartz rich, iron stained	
315	317.5	2.5	core lost	
317.5	318.5	1.0	silty mudstone, medium dark gray N4 with medium light gray N6 sandy nodules, altered edges	51
318.5	319.2	0.7	muddy sandstone, coarse, subrounded-rounded, arkosic, quartz rich, micaceous, well sorted	
319.2	320.2	1.0	silty mudstone, sharp contact, medium gray N5 with muddy and fine grained sand laminations	
320.2	322.3	2.1	muddy sandstone, fine-medium grained, fining up, arkosic, slightly micaceous, subrounded	
322.3	322.8	0.5	core lost	
322.8	323.0	0.2	muddy sandstone, medium sand, dark greenish gray 5GY 4/1, quartz rich, rounded grains	52
323	323.5	0.5	sandstone, coarse sand, light gray N7, massively bedded, subrounded, lignite layer	
323.5	327.4	3.9	core lost	
327.4	327.5	0.1	muddy sandstone, coarse medium light gray N6, arkosic, micaceous, subangular grains	53
327.5	327.7	0.2	sandy mudstone, fine grained, grayish black N2, quartz rich	
327.7	328.0	0.3	claystone, dusky brown 5 YR 2/2, well consolidated, organic rich	
328	328.2	0.2	sandstone, very coarse, dusky brown 5 YR 2/2, quartz rich rounded	
328.2	330.0	1.8	claystone, dusky brown 5YR 2/2, few laminations, organic rich, bioturbated	

330	332.1	2.1	mudstone, grayish black N2 and grayish brown 5YR 3/2, laminated	54
332.1	335.0	2.9	muddy sandstone, brownish gray 5YR 4/1 to medium dark gray N4, sand is fine to very coarse, subangular to subrounded, root traces at bottom	
335	340.1	5.1	sandy mudstone, medium gray N5, clay rich with very coarse quartz sand fining up, grains subangular, massively bedded, entire section criss-crossed with slickensides, indurated, upper 1.5' contains small lignite clasts	55
340.1	341.7	1.6	sandy mudstone, medium bluish gray 5B 5/1, very coarse sand grains, subangular, saprolitized feldspars which increase downsection	56
341.7	343.1	1.4	muddy sandstone, light gray N7 with mottles ranging from dark reddish-brown 10R 3/4 to moderate yellowish brown 10YR 6/6, very coarse sand - clear to gray, massively bedded, quartz rich	
343.1	344.9	1.8	sandy mudstone, medium dark gray N4, quartz grains pebbles to granules to v. coarse sand, rounded, mottled	
344.9	345.4	0.5	core lost	
345.4	350.4	5.0	silty mudstone mottled dark reddish brown 10YR 3/4, moderate yellowish brown 10YR 5/4, and medium light gray N6, slickensides, root traces	57
350.4	350.6	0.2	silty mudstone dark greenish gray 5G 4/1 to medium bluish gray 5B5/1, occasional mottles of dark reddish brown 10R 3/4 and moderate yellowish brown 10YR 5/4, slightly sandy 351.1-352.4, slickensides	
350.6	350.7	0.0	siderite nodule	58
350.65	354.4	3.8	silty mudstone , dark greenish gray 5G 4/1 to medium bluish gray 5b 5/1, occasional mottles of dark reddish brown 10R 3/4 and mod yellowish brown 10YR 5/4, slightly sandy 351.1-352.4, slickensides	
354.4	361.6	7.2	core lost	
361.6	361.8	0.2	silty mudstone clay plug	59
361.8	365.0	3.2	sandy mudstone, dusky yellow-green 5GY 5/2, fining upwards, medium grained, arkosic and micaceous, subrounded, poorly sorted, indurated	
365	366.3	1.3	sandstone, medium - coarse, medium dark gray N4, fining upwards, arkosic and micaceous, poorly sorted,	60
366.3	366.5	0.2	muddy sandstone, medium dark gray N4, massively bedded with feldspar / kaolinite, large black shale clast	
366.5	368.1	1.6	muddy sandstone, medium dark gray N4, fining upwards, arkosic and micaceous, poorly sorted, indurated	
368.1	369.5	1.4	sandstone, medium dark gray N4, coarse grained, fining upwards, arkosic, poorly sorted	
369.5	373.2	3.7	sandstone, dark gray N3, coarse-very coarse, fining upwards, arkosic, angular, coarse lag at base	61
373.2	377.3	4.1	mudstone, olive gray 5Y 3/2, well laminated, floating clasts (olive mudstone)	62
377.25	378.2	0.9	mudstone, grayish olive green 5GY 3/2, slickensides	

378.2	378.5	0.3	core lost	
378.5	378.8	0.3	sandy mudstone, grayish olive green 5GY 3/2, bioturbated	63
378.8	379.9	1.1	sandstone, grayish olive green 5Gy 3/2, fine-medium grained, fining upwards, poorly sorted, very angular	
379.9	380.0	0.1	carbonaceous shale	
379.95	381.7	1.8	silty mudstone, grayish olive green 5GY 3/2, pebbles, bioturbated	
381.7	383.0	1.3	muddy sandstone, medium dark gray N4, laminated	
383	383.5	0.5	core lost	
383.5	384.1	0.6	drilling mud	64
384.1	384.2	0.1	muddy sandstone, dark greenish gray 5G 4/1	
384.2	385.5	1.3	silty mudstone, dark greenish gray 5GY 4/1	
385.5	389.0	3.5	sandy mudstone, grayish olive green 5GY 3/2, micaceous, slickensides, bioturbated	65
389	390.5	1.5	muddy sandstone, grayish olive green , 5GY 3/2, micaceous, amber	
390.5	391.0	0.5	core lost	
391	395.0	4.0	sandy mudstone, grayish olive green 5GY 3/2, slickensides	66
395	395.4	0.4	drilling mud	67
395.4	397.0	1.6	sandy mudstone, grayish olive green 5GY 3/2, fining upwards	
397	398.0	1.0	muddy sandstone, dusky blue green 5BG 3/2, fine- medium sand, bioturbated	
398	398.8	0.8	sandy mudstone, dusky blue green 5BG 3/2, fine- medium sand,	
398.8	399.2	0.4	muddy sandstone, dusky blue green 5BG 3/2, fine- medium sand, micaceous	
399.2	399.3	0.1	core lost	
399.3	401.0	1.7	muddy sandstone, dark gray N3, fine grained, micaceous, brown mottles	68
401	401.9	0.9	core lost	
401.9	403.0	1.1	sandy mudstone, dark greenish gray	
403	404.2	1.2	muddy sandstone, dark greenish gray, fine grained, fining upwards, arkosic	
404.2	405.2	1.0	muddy sandstone, greenish black 5GY 2/1, arkosic, micaceous, fine grained	
405.2	406.3	1.1	core lost	
406.3	407.0	0.7	muddy sandstone, olive gray 5Y 4/1	69
407	408.5	1.5	silty mudstone, gray, laminated, bioturbated	
408.5	410.6	2.1	sandy mudstone, dusky blue green 5BG 3/2, very fine grained, micaceous	
410.6	410.7	0.1	core lost	
410.7	412.2	1.5	mudstone, dark greenish gray 5GY 4/1, micaceous, slickensides, bioturbated	70
412.2	413.9	1.7	core lost	
413.9	415.3	1.4	sandstone, light gray N6 to dark greenish gray 5GY 4/1, fining up, laminated, slickensides	
415.3	415.8	0.5	muddy sandstone, dark greenish gray 5GY 4/1	

415.8	418.3	2.5	silty mudstone, dark greenish gray 5GY 4/1, some floating clasts of clay,	71
418.3	420.0	1.7	silty mudstone, medium dark gray N4, micaceous, intraclasts, disrupted laminations, roots	72
420	421.3	1.3	mudstone, grayish black N2, carbonaceous layer	
421.3	421.4	0.1	silty mudstone, medium dark gray N4	
421.4	422.1	0.7	silty mudstone, medium gray N5 to medium light gray N6, poorly sorted, small lens of very fine sand at bottom	73
422.1	422.4	0.3	sandstone, medium light gray N6, very fine, has blocks of medium gray N5 intraclasts of mud, poorly sorted, angular, rounded	
422.4	426.8	4.4	silty mudstone, medium dark gray N5 to N6, rooted, massive, slickensides near bottom,	74
426.8	427.3	0.5	lignite, grayish black N2 - black N1, fragments only	
427.3	429.5	2.2	silty mudstone, medium light gray N6 - medium gray N5, mod well sorted at bottom, possible root traces, mottles near top	
429.5	430.9	1.4	silty mudstone, medium gray N5, some organic material in patches	
430.9	432.4	1.5	silty mudstone, grayish blue green 5BG 5/2, fining upwards, contains organic debris, lots of drilling mud, poorly sorted	75
432.4	433.2	0.8	silty mudstone, dusky blue green 5BG 3/2, fining upwards, slickensides, poorly sorted, micaceous	
433.2	434.7	1.5	muddy sandstone, grayish blue green 5BG, 5/2, coarse to fine sand - micas and quartz, fining upwards, subangular to rounded grains, mod well sorted, some laminations	
434.7	435.7	1.0	muddy sandstone, interbedded dusky blue-green 5BG 3/2 silty mudstones and medium gray N5 muddy sandstone, fine to very fine grained, kaolinitized feldspar grains, subrounded to rounded grains, mod well sorted	
435.7	436.7	0.9	silty mudstone, medium gray N5, fining upwards	76
436.65	440.7	4.1	silty mudstone, dark greenish gray 5G 4/1 and medium bluish gray 5B 5/1, fining upwards, well sorted, some mottling, root traces, slickensides present throughout, nodules at base, bioturbated	
440.7	442.0	1.3	sandy mudstone, medium dark gray N4 - medium light gray N6, fining upwards, well rounded, mod well sorted, carbonaceous roots, bioturbated	77
442	442.6	0.6	silty mudstone, medium dark gray N4 - grayish black N2, well sorted, micas and quartz grains , mottled	
442.6	443.3	0.7	core lost	
443.3	444.2	0.9	sandy mudstone, medium gray N5 - medium dark gray N4, mod well sorted, fined sand, laminations, roots, small nodules	78
444.2	446.2	2.0	silty mudstone, medium light gray N6, well sorted, root races, bioturbated	
446.2	452.6	6.4	silty mudstone, grayish blue green 5BG 5/2 - medium dark gray N4, well sorted, slickensides, mottles, some root traces	79
452.6	453.8	1.2	silty mudstone, bioturbated, organic drape at top	80
453.8	455.1	1.3	claystone	

455.1	456.0	0.9	mudstone, dark gray N3, organics	
456	456.7	0.7	core lost	
456.7	456.9	0.2	mudstone	81
456.9	457.5	0.6	silty mudstone	
457.5	459.0	1.5	lignite	
459	461.5	2.5	claystone	
461.5	462.0	0.5	core lost	
462	465.9	3.9	silty mudstone, gray N5, slight organics, red mottles scattered throughout, abundantly bioturbated, roots near bottom	82
465.9	466.5	0.6	core lost	
466.5	470.7	4.2	silty mudstone, bioturbated	83
470.7	471.8	1.1	core lost	
471.8	472.7	0.9	silty mudstone	84
472.7	474.8	2.1	silty sandstone	
474.8	476.0	1.2	sandstone	
476	476.4	0.4	core lost	
476.4	480.0	3.6	sandstone	85
480	481.4	1.4	silty mudstone medium dark gray N4, slickensides, intraclasts, organic material	
481.4	482.7	1.3	drilling mud	86
482.7	483.6	0.9	siltstone	
483.6	486.7	3.1	core lost	
486.7	488.4	1.7	sandstone, medium grained, organic material, jarosite staining, red/yellow mottles at base	
488.4	491.2	2.8	claystone, iron nodules	
491.2	491.9	0.7	core lost	
491.9	494.4	2.5	claystone, small red nodules, fossil leaves	88
494.4	494.7	0.3	claystone, medium gray N3, bioturbated	89
494.7	495.5	0.8	silty mudstone, banded silty mudstone, brownish gray 5YR 4/1, bioturbated with subhorizontal burrows	
495.5	498.7	3.2	claystone, medium gray N3, slight red mottling, bioturbated, few small red nodules, organic material throughout	
498.7	499.0	0.3	core lost	
499	500.7	1.7	claystone, medium gray N3, red nodules	90
500.7	503.8	3.1	lignite grayish black N2, lignites	
503.8	507.0	3.2	claystone, desegregated, dark gray N3	91
507	511.4	4.4	claystone, dark gray N3, some burrows	92
511.4	512.2	0.8	core lost	
512.2	513.4	1.2	silty mudstone, medium gray N5, extensive burrows near top, interbeds of silty mudstone and silty sandstone	93
513.4	514.5	1.1	muddy sandstone, medium dark gray N4, fine grained with abundant thin carbonaceous laminations	
514.5	516.5	2.0	silty mudstone, light gray N7, distorted bedding, roots	
516.5	517.8	1.3	claystone, medium gray N5, occasional dark clay clasts, red mottles	94

517.8	520.8	3.0	sandstone, black N1, organic rich, fine grained, micaceous, rounded, contains layers of dark organics, and carbonaceous bedding	
520.8	522.6	1.8	sandstone, medium gray N5, medium to fine grained, micaceous and quartz rich, rounded, occasional clasts of dark clay	95
522.6	525.0	2.4	muddy sandstone, coarse grained, very micaceous, quartz rich, rounded - subrounded,	
525	526.2	1.2	sandstone, medium bluish gray 5B 5/1, medium grained, quartz rich subangular to rounded, mod well sorted, poorly consolidated	96
526.2	526.9	0.7	muddy sandstone, dark greenish gray 5G 4/1, fining upwards, quartz rich, rounded, mod well sorted, fine grained portions	
526.9	529.9	3.0	sandstone, greenish gray 5G 6/1, fine grained, arkosic, sub rounded - rounded, well sorted, some laminations, poorly consolidated, red mottling, iron stains	
529.9	530.0	0.1	core lost	
530	533.4	3.4	muddy sandstone, medium gray N5, fine grained, micaceous, quartz rich	97
533.4	534.2	0.8	mudstone , interbedded with a lignite coal seam	
534.2	535.0	0.8	muddy sandstone, coarse grained, fining upwards, quartz rich, arkosic, subangular, poorly sorted	
535	535.4	0.4	sandstone, dark greenish gray 5GY 4/1, v coarse - coarse grained, quartz rich, some darker bedding, angular, poorly sorted	98
535.4	536.4	1.0	sandstone, very light gray N8 very coarse, interbedded with dark greenish gray 5GY 4/1, kaolinitized feldspars	
536.4	536.9	0.5	muddy sandstone, medium grained, many intraclasts (5mm- 2cm), some organic rich clasts, interbedded with micaceous rich, coarser grained sands and dark organic rich layers	
536.9	540.0	3.1	claystone, medium dark gray N4, slickensides throughout, some dark organic bits	
540	542.5	2.5	silty mudstone, dark greenish gray 5G 4/1, well sorted, some laminations, slickensides, root casts	99
542.5	543.9	1.4	silty mudstone, dark greenish gray 5G 4/1, fining upwards, quartz rich, subrounded, mod well sorted, laminated	
543.9	544.6	0.7	sandy mudstone, dusky yellowish green 5GY 5/2	100
544.6	545.0	0.4	core lost	
545	547.0	2.0	sandy mudstone, dark greenish gray 5GY 4/1	
547	547.7	0.7	muddy sandstone, dark greenish gray 5GY 4/1, fine grained	
547.7	549.5	1.8	sandstone, medium grained, arkosic, micaceous, laminated, fining upwards	
549.5	551.6	2.1	muddy sandstone, medium gray N5, fining upwards, medium sand in basal portion and fine sand in upper portion of basal unit, quartz rich, subrounded to rounded grains, moderately sorted, some laminations and organic rich thin beds	101
551.6	554.4	2.8	sandstone, medium light gray N6, very coarse, fining upwards to a fine sand, arkosic, subrounded to rounded, laminations at basal portions of unit, some thin organic layers	

554.4	555.3	0.9	sandstone, medium grained, fining upward, arkosic, some dark organic streaking	102
555.3	559.6	4.3	muddy sandstone, coarse grained, arkosic, intraclasts of green and brown clays	
559.6	564.6	5.0	sandstone, medium light gray N6, coarse, arkosic, subrounded grains, well sorted, cross bedding, kaolinization of feldspars	103
564.6	566.0	1.4	sandstone, medium grained, light gray N7, arkosic, fining upwards, micaceous	104
566	566.3	0.3	gravely sandstone, gravely to very coarse grained, quartz rich, arkosic, light gray N7	
566.3	566.5	0.2	sandy mudstone, dusky green 5G 3/2 with thin lignite seams	
566.5	566.7	0.2	sandy mudstone, grayish green 10G 4/2, clay intraclasts up to 5mm in width	
566.7	567.6	0.9	claystone, dark greenish gray 5GY 4/1	
567.6	568.5	0.9	sandy mudstone, dark greenish gray 5GY 4/1, clay pebble intraclasts, thin lignite seams, pyrite nodules up to 1cm	
568.5	568.6	0.1	gravely sandstone, light gray N7, quartz rich with pyrite nodules, medium grained, arkosic,	
568.6	569.4	0.8	sandstone, light gray N7, medium grained, arkosic	
569.4	570.3	0.9	sandstone, fine grained, slightly silty, nodule of pyrite crystals	105
570.3	571.1	0.8	silty mudstone, dusky blue green 5BG 3/2, organic wedge of woody debris, occasional lignitic material	
571.1	573.7	2.6	sand/siltstone, horizontally bedded, fine grained sandstone and siltstone, pale yellowish brown 10YR 6/2, roots cut into bedding, some graded bedding, bioturbated	
573.7	574.7	1.0	silty mudstone, grayish brown 5YR 3/2, pebbles observed, very organic, slightly micaceous, bioturbated	
574.7	576.2	1.5	claystone, dark gray N3, light gray mottle at 575.8, coal bleb at 575.2	106
576.2	577.8	1.6	mudstone, interbedded with layers of light gray tonsteins in layers ranging from 1 mm to 2 cm	
577.8	578.0	0.2	claystone, light gray	
578	579.6	1.6	core lost	
579.6	581.9	2.3	silty mudstone, dark greenish gray 5G 4/1, well sorted, some laminations with fine sand portions, 579.6-581.5 drilling mud and mudstone mixture, bioturbated, nodules	107
581.9	583.0	1.1	claystone, grayish black N2, slickensides	
583	583.7	0.7	core lost	
583.7	586.7	3.0	claystone, dark gray N3, laminated throughout, slickensides	108
586.7	588.0	1.3	silty mudstone, dark gray N3, gradational contact, becoming more silty downward	
588	588.2	0.2	silty mudstone olive gray 5Y 4/1	109
588.2	588.6	0.4	mudstone, very dusky red 10R 2/2, laminated with brown mudstone and lignitic material	
588.6	588.8	0.2	silty mudstone, pale brown 5YR 5/2, very micaceous, tonsteins, silty	

588.8	589.0	0.2	mudstone, very dusky red 10R 2/2, laminated	
589	589.1	0.1	silty mudstone, pale brown 5YR 5/2, very micaceous, tonsteins	
589.1	590.0	0.9	lignite, black N1 lignite with brown floating mudstone clasts, laminated width carbonaceous mudstone throughout	
590	591.2	1.2	mudstone, dusky yellowish brown 10 YR 2/2, laminated with dark gray silty mudstone	
591.2	591.3	0.1	core lost	
591.3	593.0	1.7	claystone, grayish black N2, interbedded with carbonaceous mudstone, well sorted, roots	110
593	593.8	0.8	mudstone, grayish black N2, contains organic fragments of woody material	
593.8	594.8	1.0	claystone, grayish black N2, interbedded with carbonaceous mudstone	
594.8	595.0	0.2	core lost	
595	596.0	1.0	claystone, pale brown 5YR 5/2. rooted, slickensides	111
596	596.1	0.0	conglomerate, zone of clay intraclasts	
596.5	596.3	0.3	silty mudstone	
596.3	597.5	1.2	silty mudstone, dark gray, horizontal laminations, vertical tube burrows up to 4 mm wide	
597.5	598.2	0.7	core lost	
598.2	599.8	1.6	silty mudstone, dark gray N3, horizontal laminations, grading into darker organic material, pyrite nodule at 598.8	112
599.8	599.9	0.1	lignite, black N1	
599.85	600.2	0.4	mudstone/lignite, grayish black N2, carb. mudstone interbedded with lignite seams	
600.2	600.5	0.3	lignite, black N1, some woody material	
600.5	600.7	0.2	mudstone, grayish black N2, interbedded with lignite	
600.7	600.8	0.1	lignite, black N1	
600.8	601.0	0.2	silty mudstone, dark yellowish brown 10 YR 4/2, micaceous, tonsteins layer	
601	601.6	0.6	drilling mud	113
601.6	602.2	0.6	lignite, black N1, some woody material	
602.2	602.3	0.1	silty mudstone, dark yellowish brown 10 YR 4/2, Tonsteins layer, micaceous, occasional lignite seams	
602.3	603.4	1.1	claystone, dark yellowish brown 10YR 4/2, organics throughout	
603.4	603.7	0.3	silty mudstone, light olive gray 5Y 5/2, contains occasional woody organics	
603.7	604.6	0.9	claystone, dark greenish gray 5GY 4/1, with occasional organic blebs, large coal at 604.3	
604.6	605.0	0.4	core lost	
605	606.9	1.9	silty mudstone, grayish green 5G 5/2, massively bedded, slickensides, some brown mottling, indurated	114
606.9	607.6	0.7	core lost	
607.6	610.1	2.5	silty mudstone, grayish green 5G 5/2, micaceous	
610.1	613.1	3.0	silty mudstone, grayish green 5G 5/2, some intraclasts	115

613.1	615.4	2.3	silty mudstone, grayish green, 10GY 5/2, micaceous, fining upwards, some organics, laminated	116
615.4	617.0	1.6	muddy sandstone, grayish green 10GY 5/2, micaceous, quartz rich, very fine grained, fining upwards, laminated	
617	618.0	1.0	core lost	
618	618.4	0.4	muddy sandstone, grayish blue green 5BG 5/2, very fine grained, micaceous, quartz rich, laminated	117
618.4	618.6	0.2	muddy sandstone, grayish blue green 5BG 5/2, pebble sized clasts of mudstone (same color) floating	
618.6	621.9	3.3	muddy sandstone, medium gray N5, fine grained, quartz, well sorted, well developed laminations with some cross-bedding	
621.9	623.0	1.1	sandstone, medium light gray N6, medium sand, subrounded, quartz rich, micaceous, laminated, lignite clasts at top	
623	623.3	0.3	sandstone, very light grayN8, medium-fine grained, arkosic, micaceous, quartz rich, some organic laminations	118
623.3	623.4	0.1	sandstone, coarse-very coarse grained, quartz, arkosic, micaceous with organic seams	
623.4	624.0	0.6	sandstone, med.-fine grained as above	
624	624.3	0.3	muddy sandstone, medium grained, argillaceous, pale yellowish brown 10YR 6/2, organic laminations	
624.3	628.2	3.9	core lost	
628.2	629.8	1.6	silty mudstone, greenish gray 5GY 6/1, fining upwards, micaceous, well sorted, laminated, slickensides	119
629.8	632.8	3.0	muddy sandstone, greenish gray 5GY muddy sandstone, fining upwards, fine grained, quartz rich, micaceous, rounded, moderately well sorted, laminated, crossbedding, some thin organic rich lenses,	
632.8	634.4	1.6	muddy sandstone, medium gray N5, very fine grained, organic laminations	120
634.4	635.2	0.8	muddy sandstone, medium grained, arkosic, fining upward, some organic layering	
635.2	635.4	0.2	muddy sandstone, organic laminations	
635.4	636.7	1.3	claystone, medium dark gray N5, many lignitic laminations	
636.7	637.5	0.8	core lost	
637.5	638.0	0.5	mudstone, dark yellowish brown 10YR 4/2, organic rich, lignitic in center	121
638	638.7	0.7	mudstone, brownish black 5YR 2/1, heavily laminated with lignite, woody material present	122
638.7	642.5	3.8	core lost	
642.5	643.0	0.5	drilling mud	123
643	645.0	2.0	claystone, dark gray N3, large black clay blebs, horizontal laminations	
645	648.6	3.6	claystone, dark gray N3, fossil leaves in very basal end, organic matter scattered throughout, horizontal laminations present	124
648.6	648.7	0.1	silty mudstone, dark gray N3	125

648.7	652.3	3.6	sandy mudstone, medium gray N5, fine grained, quartz rich rounded grains, moderately well sorted, laminations, basal portion of unit contains organic rich laminations, burrows, fine grained silt/mud lenses occur between 649.8-651.5,	
652.3	653.0	0.7	muddy sandstone, medium dark gray N4, fining upwards, quartz rich with abundant organics, subangular-subrounded grains, moderately well sorted, laminations	
653	653.3	0.3	sandstone, medium light gray N6, coarse grained, quartz rich subrounded to rounded	
653.3	653.8	0.5	core lost	
653.8	655.5	1.7	muddy sandstone, medium grained, medium gray N5, arkosic, quartz rich, micaceous	126
655.5	655.7	0.2	muddy sandstone, contains organic laminations	
655.7	656.2	0.5	mudstone, gray mudstone grading into carbonaceous mudstone and lignitic material	
656.2	657.0	0.8	muddy sandstone, medium grained, marbled with organic material from above unit, micaceous, arkosic	
657	658.6	1.6	lignite, lignitic material, basal end consisting of coal, some woody material	
658.6	659.1	0.5	core lost	
659.1	661.1	2.0	lignite, black N1, massive lignite bed with some thin sand laminations at 660.0, well sorted	127
661.1	661.8	0.7	sandy mudstone, medium dark gray N4, coarse sand, quartz, slightly micaceous, subrounded grains, massive layers	
661.8	664.4	2.6	core lost	
664.4	665.5	1.1	claystone, dark greenish gray 5G 4/1, organic material dispersed throughout	128
665.5	666.0	0.5	muddy sandstone, fine grained, organic material throughout, reworked clay blebs, olive gray 5Y 4/1	
666	666.4	0.4	claystone, dark greenish gray 5G 4/1, organic material dispersed throughout	
666.4	668.6	2.2	muddy sandstone, very slightly silty mudstone, medium bluish gray 5B 5/1, slicks and organic debris throughout, moderately well sorted, rooted	129
668.6	670.4	1.8	core lost	
670.4	672.4	2.0	silty mudstone, medium bluish gray 5B 5/1, silty mudstone, predominately clay, drillers reported swelling, slicks and organics throughout with roots, moderately well sorted,	130
672.4	676.2	3.8	core lost	
676.2	676.8	0.6	silty mudstone, medium bluish gray 5B 5/1, slightly silty mudstone, predominately clay, slicks, organics scattered throughout, well sorted	131
676.8	677.2	0.4	muddy sandstone, medium dark gray N5, very coarse with quartz grains, poorly sorted, may contain large quantities of drilling mud	

677.2	679.2	2.0	silty mudstone, medium bluish gray 5B 5/1, slightly silty, predominately clay, slicks and organic debris, root traces, some big woody chunks, may contain drilling mud	
679.2	679.4	0.2	muddy sandstone, medium bluish gray 5B 5/1, very fine grained with some mud, quartz, poorly sorted, organics	
679.4	679.7	0.3	silty mudstone, medium bluish gray 5B 5/1, slightly silty, organics	
679.7	680.9	1.2	core lost	
680.9	681.2	0.3	silty mudstone, medium bluish gray, slightly silty, contains organics, actual roots, slickensides	132
682.3	682.8	0.5	silty mudstone, 5G 5/1 silty mudstone with few very coarse grains, slickensides and organics	
682.8	683.3	0.5	sandstone, very fine grained, light bluish gray 5B 7/1, quartz rich, organics present	
683.3	683.5	0.2	sandstone, brownish gray 5YR 4/1, very fine-medium grained, very brown, poorly sorted, laminated, unusual white grains of medium sized sand	
683.5	684.4	0.9	silty mudstone, light bluish gray 5B 7/1, to medium bluish gray 5B 5/1, some slicks, organics, few coarse grains	133
684.4	687.5	3.1	sandstone, medium bluish gray 5B 5/1, coarse sandstone, fining upward, organics and roots throughout, quartz and micaceous, organic material is in bedding planes.	
687.5	688.1	0.6	muddy sandstone, medium gray N5, medium sand, micaceous, quartz rich, arkosic, rounded, lignite bands	134
688.1	691.6	3.5	core lost	
691.6	691.9	0.3	muddy sandstone, medium light gray N6, medium-coarse grained, quartz rich, micaceous, subangular, moderately well sorted	
691.9	692.5	0.6	silty mudstone, medium light gray N6, massively bedded	
692.5	695.5	3.0	muddy sandstone, light olive gray 5Y 6/1, very fine grained, subrounded, moderately well sorted, fining upwards, micaceous	135
695.5	696.1	0.6	muddy sandstone, cycles of muddy sandstone and silty mudstone, fining upwards	136
696.1	696.2	0.1	silty mudstone, medium gray N5, micaceous, massively bedded	
696.2	705.0	8.8	muddy sandstone, medium gray N5, fine sand, subrounded, well sorted, micaceous	
705	710.0	5.0	sandstone, very light gray N8 , medium gray N5, and grayish black N2, fine sand, quartz, micas create laminations	138
710	711.2	1.2	sandstone, medium light gray N6, fining upwards, subangular to subrounded, quartz, poorly developed laminations, lignite layers	139
711.2	711.5	0.3	core lost	
711.5	714.7	3.2	claystone, greenish gray 5G 6/1, massively bedded, slickensides in fractures	
714.7	714.9	0.2	mudstone, olive black 5Y 2/1, massive, organic rich	140
714.9	715.0	0.1	claystone, medium gray N5, massive, slickensides	
715	716.0	1.0	silty mudstone, light olive gray 5Y 6/1, micaceous, massive	
716	716.6	0.6	claystone, medium gray N5, massive, slickensides	

716.6	717.0	0.4	silty mudstone, light olive gray 5Y 6/1, micaceous, massive	
717	717.3	0.3	claystone, medium gray N5, massive, slickensides, poorly consolidated	
717.3	719.5	2.2	silty mudstone, light olive gray 5Y 6/1, massive, micaceous, floating lignite clasts	
719.5	719.7	0.2	claystone, medium gray N5, massive, slickensides	141
719.7	720.7	1.0	mudstone, grayish brown 5YR 3/2, mottled browns and blacks, organic rich, increasing amounts of lignite with depth, laminated	
720.7	729.5	8.8	lignite, grayish brown N2 to brownish black 5YR 2/1, interbedded layers of lignite rich claystone and pure claystone, leaves and plant material	142-143
729.5	730.5	1.0	drilling mud	
730.5	731.7	1.1	lignite, black N1, some brownish vague bedding	
731.65	731.8	0.1	silty mudstone, moderate brown 5YR 4/4, tonstein layer interbedded with lignite	
731.75	734.4	2.6	lignite, black N1, some brownish vague bedding, whitish blebs	
734.4	734.5	0.1	silty mudstone, yellowish gray 5Y 8/1, bluish white tonstein layer 5B 9/1	
734.5	735.3	0.8	lignite, black N1, vertical fractures	144
735.3	735.7	0.4	silty mudstone, horizontal laminations of lignite and tonstein	
735.7	741.2	5.5	lignite, black N1	145
741.2	742.2	1.0	claystone, dark gray N3, gradational contact into claystone, laminated with lignite	
742.2	742.8	0.6	lignite, laminated with claystone	
742.8	743.3	0.5	drilling mud	146
743.3	744.8	1.5	core lost	
744.8	746.8	2.0	silty mudstone, dark gray N3, organics present throughout, laminations at base	
746.8	747.6	0.8	claystone, medium dark gray N4, black organics present, slightly laminated at base	
747.6	749.5	1.9	silty mudstone, medium dark gray N4, some black organic horizontal threads	147
749.5	750.0	0.5	claystone, dark gray N3, thin coal seams grading into lighter colored claystone, medium gray N5, slickensides, small organic fragments throughout	
750	755.0	5.0	claystone, medium gray N4, horizontal laminations throughout, laminations disturbed on basal end	148
755	758.7	3.7	silty mudstone, dark gray N3, with medium gray N5 laminations	149
758.7	758.8	0.1	lignite, black N1	
758.8	760.0	1.2	silty mudstone, dark gray N3, with medium gray N5 laminations	
760	762.9	2.9	silty mudstone, medium dark gray N4 with medium light gray N6 laminations - some disrupted, organic rich	150
762.9	763.0	0.1	lignite, lignite seam ~1 cm wide, other organics present - roots with root hairs, some woody material	
763	765.0	2.0	silty mudstone, medium dark gray N4 with medium light gray N6 laminations - some disrupted, organic rich	

765	765.4	0.4	drilling mud	151
765.4	766.4	1.0	claystone, dark gray N3, organic rich bands	
766.4	766.5	0.1	mudstone, brownish black 5YR 2/1, laminated with organic material	
766.5	767.0	0.5	claystone, medium dark gray N4, root traces	
767	768.5	1.5	drilling mud	
768.5	768.9	0.4	claystone, medium dark gray N4, contains many small organic fragments	
768.9	769.8	0.9	core lost	
769.8	770.0	0.2	drilling mud	152
770	774.3	4.3	claystone, medium gray N5, with dark gray N3 laminations, roots and some disrupted laminations, floating organics	
774.3	774.5	0.2	core lost	
774.5	775.1	0.6	sandy mudstone, medium gray N5, contains organic matter	153
775.1	777.0	1.9	silty mudstone, medium gray N5, slickensides, laminated with medium light gray N6	
777	777.6	0.6	claystone, medium gray N5	
777.6	778.0	0.4	drilling mud	
778	779.0	1.0	mudstone, brownish black 5YR 2/1, black organic traces, some whitish compressed aggregations, grades into very fine tonstein layers and black organic laminations	
779	784.5	5.5	lignite, grayish black N2 to black N1, weakly lustrous, some bands of micaceous sand, silt beds, vermiform kaolinite	154
784.5	784.8	0.3	sandy mudstone, medium dark gray N4, coarse-grained, quartz, subangular, moderately well sorted, poorly consolidated	155
784.8	785.5	0.7	lignite, grayish black N2, moderately well sorted, laminations	
785.5	787.7	2.2	claystone, upper portion is dark gray N3, lower portion is medium bluish gray 5b 5/1, fining upwards sequence, well sorted	
787.7	788.8	1.1	silty mudstone, greenish gray 5G 6/1, silty mudstone, fining upwards, quartz and mica rich, moderately well sorted, subrounded grains	
788.8	789.5	0.7	core lost	
789.5	802.0	12.5	silty mudstone, silt-filled burrows common (2-4 cm), burrows at top of section are long, pale olive 10Y 6/2, weakly bedded to well bedded in some areas, thin coal laminations and plant material located on the spit-face of the core, small coal bed at 791.5 (approx. 1 cm),156-159	
802	802.2	0.2	sandstone, very fine grained, medium light gray N6	
802.2	805.9	3.7	silty mudstone	
805.9	807.7	1.8	claystone, medium dark gray N4, occasional light gray silt blebs (~0.05')	160
807.7	808.6	0.9	mudstone, fine organic laminae, grayish black N2	
808.6	814.6	6.0	claystone, grayish black N2 to medium dark gray N4. At 810.7, color shifts to dark gray N2 to black N1, laminated in layers (1 cm)	161
814.6	815.6	1.0	core lost	
815.6	816.2	0.6	sandy mudstone, medium dark gray N4, massive, poorly consolidated, mixed with drilling mud	162

816.2	817.9	1.7	mudstone, grayish black N2, well sorted, organic-rich laminations, woody material	
817.9	818.4	0.5	sandy mudstone, medium dark gray N4, mixture of mudstone and drilling mud	
818.4	818.7	0.3	mudstone, medium dark gray N4, well sorted	
818.7	818.8	0.1	core lost	
818.8	820.3	1.5	sandstone, medium dark gray N4, coarse sand granules in a mud matrix, some quartz and rounded bits of mud and/or shale, fining upwards	163
820.3	820.4	0.1	mudstone, dark gray N3 to grayish black N2	
820.4	820.5	0.1	tonstein, coarse grained 3/4" parting, sharp boundaries with surrounding mudstone, subangular clay granules and pebbles	
820.5	821.7	1.2	mudstone, dark gray N3 to grayish black N2, organic rich laminations	
821.7	822.3	0.6	lignite, black N1, intermixed drilling mud	
822.3	826.8	4.5	claystone, medium dark gray N5 to dark gray N4, slickensides present, organics, well sorted, massive	164
826.8	829.5	2.7	core lost	
829.5	830.6	1.1	silty mudstone , dark gray N3, fine laminations, thin organic layers	165
830.6	830.9	0.3	sandy mudstone, dark gray N3, mixture of drilling mud and coarse to granule size sand with fragments of silty mudstone	
830.9	831.7	0.8	drilling mud	166
831.7	833.6	1.9	claystone, dark gray N3, well sorted with some fine sand and silt lenses, laminated, possible leaves, a few clay-rich blebs	
833.6	835.1	1.5	lignite, black N1, contains thin light brownish gray 5YR 6/1 laminations, well sorted	
835.1	835.5	0.4	claystone, dark gray N3, well sorted, some thin laminations (<0.25 cm)	
835.5	839.2	3.7	silty mudstone, dark gray N3, fine laminations, well sorted, thin organic layers, poorly consolidated	167
839.2	839.5	0.3	core lost	
839.5	843.2	3.7	claystone, fissile, well bedded, organic rich laminations, rip up clasts, tonstein layers	168
843.2	844.5	1.3	silty mudstone, interbedded with small layers of tonstein and organic rich layers, rip-up clasts, slickensides	
844.5	844.6	0.1	claystone	169
844.6	844.8	0.2	sandstone, fine grained, long burrow ~6cm, roots	
844.8	847.7	2.9	claystone, dark gray N3, slickensides, small layers of siltstone, and organics	
847.7	849.5	1.8	sandstone, medium light gray N6, fine sand, well sorted, quartz rich, organic root traces, burrows, bedded	
849.5	850.5	1.0	drilling mud	170

850.5	854.5	4.0	sandstone, medium dark gray N4, very fine and fine sand, well sorted, wavy horizontal bedding, small layers of tonstein within section, organic root traces cut through bedding, fossil leaves	
854.5	854.6	0.1	silty mudstone	171
854.6	856.1	1.5	sandstone, fine sand, quartz rich, coarsening upwards slightly	
856.1	856.9	0.8	siltstone, well developed horizontal and wavy bedding, horizontal burrow filled with fine sand	
856.9	857.0	0.1	claystone, carbonate cement	
857	857.9	0.9	siltstone, well developed horizontal and wavy bedding	
857.9	858.0	0.1	claystone, carbonate cement	
858	858.5	0.5	siltstone , well developed horizontal and wavy bedding	
858.5	859.5	1.0	core lost	
859.5	860.9	1.4	siltstone, well developed horizontal and wavy bedding	172
860.9	861.5	0.6	claystone, dark gray N3, organic rich, unconsolidated	
861.5	861.9	0.4	siltstone, medium light gray N6	
861.85	864.0	2.1	siltstone, laminated, dark gray N3, organic rich	
864	864.3	0.3	claystone, dark gray N3	173
864.3	868.0	3.7	core lost	
868	868.2	0.1	sandstone, very fine sand	174
868.2	868.8	0.6	siltstone, horizontal bedding, slickensides	
868.8	871.5	2.7	sandstone, very fine sand, organic root traces, bedding destroyed by bioturbation	
871.5	872.2	0.7	siltstone, medium dark gray N4	175
872.2	873.0	0.8	core lost	
873	873.2	0.2	siltstone, medium dark gray N4	
873.2	873.5	0.3	core lost	
873.5	875.0	1.5	claystone, top 0.4' ripped up from drilling, medium gray N5, horizontal bedding, fissile	176
875	876.9	1.9	siltstone, interbedded layers, white blebs or horizontal burrows	
876.9	877.1	0.2	claystone	
877.1	877.3	0.2	sandstone, fine sand	
877.3	878.5	1.2	siltstone, horizontal bedding, burrows and bioturbation, tonstein, brown blebs	
878.5	880.0	1.5	core lost	177
880	881.6	1.5	claystone, fining upwards, horizontal and wavy bedding, fissile, slickensides	
881.55	883.2	1.7	siltstone, well laminated wavy bedding, organic material - quantity fining upwards, bioturbation, lignite layer interlaminated at 882.7'	
883.2	883.5	0.3	core lost	
883.5	886.6	3.1	siltstone, light gray N7, interlaminated, slickensides, organic material, root traces disrupting bedding	178
886.6	887.2	0.6	sandstone, fine grained clean sand	
887.2	887.8	0.6	siltstone	179
887.8	890.5	2.7	mudstone, light gray N7, coarsening upwards sequence, organics within layer	

890.5	893.2	2.7	core lost	
893.2	895.5	2.3	siltstone, some organic material, bioturbated, brown fine sandstone clasts	180
895.5	900.2	4.7	silty mudstone, chaotic bedding, hard yellow clasts - clay banding in middle and bottom, organics	181
900.2	901.5	1.3	core lost	
901.5	902.3	0.8	siltstone, medium light gray N6	182
902.3	902.8	0.5	sandstone, interbedded with siltstone, very fine sand, fining upwards, poorly sorted, wavy bedding,	
902.8	905.0	2.2	lignite, grayish black N2, tonstein layers, thin clay layers	
905	905.6	0.6	drilling mud	183
905.6	905.8	0.2	lignite grayish black N2, tonstein layer	
905.8	906.9	1.1	sandstone, medium dark gray N4, medium sands, coarsening upwards, bedding disturbed by roots	
906.9	908.1	1.2	silty sandstone, medium light gray N6, wavy bedding	
908.1	910.3	2.2	claystone, medium dark gray N4, slickensides, organic material	184
910.3	911.7	1.4	siltstone, medium light gray N6, some bedding, roots, bioturbation	
911.7	911.8	0.1	sandstone, medium gray N5, fine sand, bedding	
911.8	914.5	2.7	core lost	
914.5	917.5	3.0	sandstone, fine sand, horizontally wavy bedding, organic laminations, medium sorted, tonstein in middle,	185
917.5	919.5	2.0	core lost	186
919.5	919.9	0.4	drilling mud	
919.9	920.6	0.7	sandstone, medium light gray N6 to medium gray N5, fining upward fine sand to silty mudstone organics	
920.6	921.8	1.2	silty mudstone, dark gray N3 to grayish black N2, parallel bedding, organic rich at base, roots, slickensides,	
921.8	922.1	0.3	silty mudstone, medium gray N5 - some pinkish areas, layers of tonsteins and organics	
922.1	922.7	0.6	lignite, black N1, tonstein layers	
922.7	923.0	0.3	silty mudstone, medium gray N5, slickensides, organics	187
923	924.4	1.4	drilling mud	
924.4	925.6	1.2	silty mudstone, medium gray N5 to medium bluish-gray 5B 5/1, silty mudstone, thin light colored bands	
925.6	926.1	0.5	silty mudstone, medium dark gray N4, contains drilling mud	188
926.1	927.8	1.7	sandstone, medium gray N5 to medium dark gray N4, fine to very fine sand, well sorted, angular to rounded, quartz and mica rich, organic debris along bedding planes, slight cross-bedding	
927.8	928.0	0.2	core lost	
928	930.6	2.6	drilling mud	189
930.6	932.0	1.4	silty mudstone, medium gray N5 to grayish black N2, fine parallel laminae, contorted bedding, horizontal tubules	
932	933.2	1.2	core lost	

933.2	935.4	2.2	silty mudstone, medium gray N5 to dark gray N3 some laminations, organics throughout, slickensides near bottom, color at bottom: grayish black N2	190
935.4	936.5	1.1	core lost	
936.5	941.5	5.0	silty mudstone, medium light gray N6 to grayish black N2 - lightens downward, alternating light/dark thin laminations in top becoming mottled, organics throughout, slickensides	191
941.5	944.7	3.2	mudstone, medium light gray N6, bedding with organics, some layers of coarser sediment, poorly sorted, quartz and mica rich	192
944.7	945.0	0.3	silty mudstone, medium dark gray N4, v fine sand at base, organics throughout	
945	947.7	2.7	silty mudstone, medium gray N5 to dark gray N5 with thin horizontal lenticular blotches of yellowish gray 5Y 7/2, thin slices of lignite matter at various orientations on internal surfaces, laminated	193
947.7	949.4	1.7	muddy sandstone, medium gray N5, muddy, fine grained, with thin, irregularly spaced, horizontal lignitic laminations	
949.4	950.0	0.6	core lost	
950	951.5	1.5	sandstone, fine grained, small organic laminations, poorly sorted, horizontal bedding, visible lenses of muddy sandstone	194
951.5	952.6	1.1	siltstone, small sandstone and clay-rich laminations	
952.6	954.5	1.9	lignite, some minor silty layers intermingled for 0.8', tonstein observed	
954.5	956.0	1.5	lignite, interbedded with silts and claystone (nice layers), grayish black 2N2	195
956	957.3	1.3	silty mudstone, organic root traces, light gray N6 to medium light gray N7, interbedded with small layer of sandy mudstone followed by organic rich claystone	
957.3	959.6	2.3	siltstone, horizontal and wavy bedding, organic root traces abundant	
959.6	962.5	2.9	silty mudstone, interbedded silt, sand and clay, small wavy laminations, some organic material, fine sand layer, some small horizontal burrows at 960.0, lignite and organics at end.	196
962.5	965.2	2.7	silty mudstone, medium gray N5, organic rich, lignite seams, wavy bedding, clay clast 2.5 cm, organic material, bioturbated,	197
965.2	965.5	0.3	lignite, black N1	
965.5	965.9	0.4	claystone	
965.9	966.4	0.5	core lost	
966.4	967.5	1.1	siltstone, medium gray N5bedding evident, but likely some bioturbation,	
967.5	968.4	0.9	siltstone, medium dark gray N4, nice bedding, burrows,	198
968.4	970.0	1.6	sandstone, very light gray N8, to light gray N7, fine grained, very consolidated, nice horizontal bedding, horizontal burrows which have been filled with calcite and a claystone lens which intersects the burrows	

970	972.5	2.5	muddy sandstone, medium dark gray N4, silty, muddy sandstone with some clay rich laminations and organics, some bedding observed, slightly fining upwards	
972.5	973.5	1.0	sandstone, very fine grained, medium light gray N6	199
973.5	973.6	0.1	claystone, light yellow clay band, potentially bentonite or carbonaceous claystone bands.	
973.6	974.6	1.0	muddy sandstone, fine grained, interlaminated with organic material	
974.6	974.7	0.1	claystone, light yellow clay bands	
974.7	977.5	2.8	sandstone, fine-medium grained, medium gray N5, some silt, organic rich laminations, horizontal and wavy laminations	
977.5	978.0	0.5	muddy sandstone, lt. gray N7, organic rich laminae,	200
978	980.5	2.5	sandstone, lt. gray N7, fine grained, quartz rich fines upwards, black organic stringers in middle	
980.5	980.6	0.1	mudstone, med. lt. gray N6	
980.6	981.3	0.7	siltstone, med. lt. gray N6-med. gray N5, weakly laminated	
981.3	982.2	0.9	muddy sandstone, yellowish gray 5Y 7/2, fine grained, laminated, fining upwards, organic rich stringers	
982.2	982.5	0.3	core lost	
982.5	983.5	1.0	sandstone, med. gray N6very fine grained, , cross-bedded, climbing ripples	201
983.5	984.4	0.9	silty mudstone, med. dark gray N4, horizontal and wavy bedding with organic layers, bioturbation	
984.4	984.5	0.1	sandstone, fine grained	
984.5	984.7	0.2	siltstone	
984.7	985.2	0.5	lignite, grayish black N2	
985.2	986.3	1.1	core lost	
986.3	990.3	4.0	lignite, black N1 with sandy or tonstein partings about 0.1' thick each	202
990.3	991.0	0.7	claystone	
991	991.3	0.3	core lost	
991.3	992.0	0.7	claystone	203
992	995.5	3.5	lignite, pyrite nodule at 992.3, sand stringer at 992.5	
995.5	997.0	1.5	muddy sandstone, massive, organic rich, fining upwards, pyrite at 995.7, olive gray 5Y 3/2	204
997	1000.0	3.0	sandstone, fine-grained, massive, fining upwards, sulfide nodules at 997.5-999.5, lt. olive gray 5Y 5/2, rare feldspars degrading to clay	
1000	1000.2	0.2	claystone, lt. gray N7	205
1000.2	1002.0	1.8	sandstone, lt. gray N6,very fine, well-sorted	
1002	1005.0	3.0	sandstone, med. dark. gray N4, fining upwards to claystone	
1005	1005.9	0.9	claystone, slightly silty interbeds, med. dark. gray N4	206
1005.9	1007.1	1.2	sandstone, med. gray N5, fine-grained, fining upwards, wavy laminations	
1007.1	1008.2	1.1	sandstone, med. gray N5,coarse grained, mod. well-sorted, horizontal laminations	
1008.2	1008.5	0.3	lignite, one claystone parting	

1008.5	1009.2	0.7	muddy sandstone, grayish green 10GY 5/2, extensive bioturbation and soft sediment deformation	207
1009.2	1011.8	2.6	silty mudstone, grayish olive10Y 4/2, slickensides, mottles, fining upward	
1011.8	1012.5	0.7	sandstone, grayish olive 10Y 4/2, soft sediment deformation,	
1012.5	1014.5	2.0	silty mudstone, dusky yellow green 5GY 5/2 to grayish olive green 5GY, massive	208
1014.5	1015.3	0.8	mudstone, med. dark gray N4	
1015.3	1016.7	1.4	lignite, some slickensides	
1016.7	1017.4	0.7	silty mudstone, med. gray N5, laminated, some burrows, slickensides	
1017.4	1018.5	1.1	sandstone, burrowed	
1018.5	1019.1	0.6	claystone, burrowed	209
1019.1	1019.7	0.6	mudstone, interbeds with large nodules (up to 8 cm)	
1019.7	1020.5	0.8	lignite, grayish black N2, slickensides, some pyrite, minor clay interbeds,	
1020.5	1021.3	0.8	sandstone, medium lt. gray N6, poorly sorted, angular,	
1021.3	1022.8	1.5	nodule , very lt. gray N8	
1022.8	1026.8	4.0	sandstone, medium gray 5/N5, fine-medium grained, some clay	210
1026.8	1027.0	0.2	core lost	
1027	1027.9	0.8	lignite, slickensides and pyrite	211
1027.8	1032.0	4.2	claystone, slickensides, burrow at 1029.9, carbonate cementation at 031-1032	
1032	1032.6	0.6	silty mudstone, dark gray N3	212
1032.6	1033.8	1.2	silty mudstone, med. lt. gray N5, whitish blebs and convolute bedding	
1033.8	1034.6	0.8	silty mudstone, dark gray N3 to medium dark. gray N4, slickensides throughout with organic debris on bedding planes	
1034.6	1034.7	0.1	core lost	213
1034.7	1036.1	1.4	sandstone, very fine grained, micaceous, med. dark. gray N4 to med. lt. gray N6, bioturbated	
1036.1	1039.4	3.3	silty mudstone, grayish black N2, lightening upwards to med. dark. gray N4, slickensides throughout	
1039.4	1040.1	0.7	drilling mud	214
1040.1	1043.0	2.9	silty mudstone, med. lt. gray N6 with patches of med. dark. gray N4, convolute bedding	
1043	1044.0	1.0	silty mudstone, med. dark. gray N4, with slickensides, fining upwards	
1044	1048.8	4.8	sandstone, lt. gray N7 to dark gray N3, very fine grained, micaceous, cross-bedding at 1045.5, clay lens at 1047.5	215
1048.8	1049.0	0.2	core lost	
1049	1049.2	0.2	sandstone, dark gray N3 to med. gray N5, fine to med. grained, micaceous	216
1049.2	1049.3	0.1	claystone, with lignite fragments	
1049.3	1054.0	4.7	sandstone, dark gray N3 to med. gray N5, fine to med. grained, micaceous	

1054	1054.7	0.7	muddy sandstone, med. dark. gray N4, organic laminations, poorly sorted	217
1054.7	1054.8	0.1	sandstone, med. lt. gray N6, med. grained	
1054.8	1055.5	0.7	muddy sandstone, med. dark. gray N4, organic laminations, poorly sorted, leaf fossil at 1055.3	
1055.5	1056.7	1.2	sandstone, lt. gray N7-very lt. gray N8,med. to coarse, massive, poorly sorted, some organics, angular to rounded	
1056.7	1059.2	2.5	core lost	
1059.2	1060.8	1.6	sandstone, lt. gray N7 to dark gray N3, fine-coarse grained, massive, subrounded to subangular, minor mica, intermittent thin lignites	218
1060.8	1061.0	0.2	sandstone, coarse grained and bounded by lignitic layers	
1061	1062.1	1.1	sandstone, coarse grained, light gray N7 to dark gray N3, massive, subrounded to subangular, minor mica, intermittent thin lignites	
1062.1	1062.3	0.2	lignite	
1062.3	1063.3	1.0	sandstone, medium grained	
1063.3	1063.8	0.5	sandstone, grayish black N2- grayish olive green 5GY 3/2, very coarse grained, poorly sorted, with kaolinite blebs,	219
1063.8	1067.3	3.5	core lost	
1067.3	1067.6	0.3	sandstone, med. gray N5, medium grained	220
1067.6	1069.3	1.7	silty mudstone, med. dark. gray	
1069.3	1069.8	0.5	muddy sandstone, med. gray N6, mixed with drilling mud	
1069.8	1072.3	2.5	muddy sandstone, med. dark. gray N4, horizontal bedding planes, soft sediment deformation	
1072.3	1072.8	0.5	silty mudstone, med. dark. gray N4, mixed with drilling mud	221
1072.8	1073.9	1.1	mudstone, med. dark. gray N4 to grayish black N2, fining upwards from fine sand, leaf fossils	
1073.9	1076.3	2.4	muddy sandstone, med. gray N5, fine grained, coarsening upwards	
1076.3	1076.5	0.2	sandy mudstone, med. dark. gray N4	222
1076.5	1079.8	3.3	silty mudstone, dark. gray N3	223
1079.8	1080.0	0.2	sandy mudstone, greenish gray 5GY 6/1, moderately well sorted	
1080	1081.1	1.1	silty mudstone, med. bluish gray 5B 5/1 silty mudstone and greenish gray 5GY 6/1 alternating beds, soft sediment. deformation, burrows	
1081.1	1083.0	1.9	silty mudstone, med. bluish gray 5B 5/1	
1083	1084.5	1.5	silty mudstone, lt. gray, chaotic bedding in places	224
1084.5	1084.6	0.1	mudstone	
1084.6	1086.5	1.9	siltstone, lt. gray, roots	
1086.5	1087.5	1.0	sandy mudstone, med. lt. gray, moderately well-sorted, soft sediment deformation	225
1087.5	1089.7	2.2	silty mudstone, med. bluish gray 5B 5/1	
1089.7	1090.4	0.7	mudstone	
1090.4	1091.6	1.2	lignite, black N1	
1091.6	1092.2	0.6	sandy mudstone, very fine grained with interbedded silt	226
1092.2	1094.7	2.5	claystone, horizontal bedding, roots	
1094.7	1095.7	1.0	siltstone, soft sediment deformation	
1095.7	1095.9	0.2	claystone	

1095.9	1096.5	0.6	core lost	
1096.5	1097.4	0.9	siltstone, med. dark. gray N4, with thin lignites	227
1097.4	1098.4	1.0	sandy mudstone	
1098.4	1101.0	2.6	core lost	
1101	1102.8	1.8	silty mudstone, med. light gray N6 to med. gray N5, horizontal laminations, slickensides at base	228
1102.8	1104.1	1.3	siltstone, med. dark. gray N4	229
1104.1	1105.2	1.1	sandy mudstone, med. lt. gray N6, very fine grained, granules at 1104.6	
1105.2	1107.4	2.2	silty mudstone, grayish black N2,med. dark. gray, thinly bedded	
1107.4	1107.5	0.1	lignite	
1107.5	1108.6	1.1	claystone, dark. gray N3, slickensides, rip up clasts (2-5cm) from 1107.5 to 1107.9	230
1108.6	1108.7	0.1	lignite, brownish black 5YR 2/1	
1108.7	1112.0	3.3	claystone, dark. gray N3, grayish black N2 at base, 0.1' sand at 1111.5	
1112	1119.1	7.1	silty mudstone, med. dark. gray N4, floating lignite clasts, slickensides	231 232
1119.1	1119.7	0.6	sandy mudstone, dark. gray N3	
1119.7	1120.2	0.5	core lost	
1120.2	1120.8	0.6	silty mudstone, greenish gray 5GY 6/1, slickensides, convolute bedding	233
1120.8	1124.0	3.2	claystone, greenish gray 5GY 6/1 and very pale orange 10YR 8/2	
1124	1125.0	1.0	mudstone, grayish brown 5YR 3/2, slickensides	
1125	1126.7	1.7	sandy mudstone, med. gray N5 to med. N6, root traces, sand-filled burrows	234
1126.7	1127.3	0.6	silty mudstone, med. light gray N6	
1127.3	1127.6	0.3	lignite, with tonsteins	
1127.6	1130.0	2.4	silty mudstone, grayish black N2, fissile	
1130	1130.9	0.9	lignite	235
1130.9	1131.0	0.1	mudstone, brownish gray 5YR 4/1	
1131	1132.0	1.0	silty mudstone, med. gray N5	
1132	1132.9	0.9	silty mudstone, grayish black N2	236
1132.9	1134.2	1.3	siltstone, med. dark gray N4 with med. gray N5, bioturbated	
1134.2	1135.0	0.8	siltstone, med. dark gray N4 with med. gray N5 laminations, layers very thin and horizontal	
1135	1135.6	0.6	siltstone, med. gray N5 with distorted laminations, laminations	
1135.6	1135.7	0.1	claystone, dark. gray N3, finely laminated	
1135.7	1136.2	0.5	claystone/siltstone, interbedded dark. gray N3 claystone and medium dark gray N4 silty mudstone	
1136.2	1137.4	1.2	claystone, grayish black N2, silty at base	237
1137.4	1138.8	1.4	siltstone, med. dark. gray N4	
1138.8	1141.2	2.4	silty mudstone, med. gray N5	
1141.2	1143.0	1.8	siltstone, med. gray N5	238
1143	1143.5	0.5	silty mudstone, med. dark. gray N4	

1143.5	1143.8	0.3	mudstone	
1143.8	1143.9	0.0	lignite	
1143.8	1144.5	0.7	claystone, med. dark. gray N4	
1144.5	1146.0	1.5	sandstone, interbedded laminations, N4 to N2	
1146	1146.4	0.4	siltstone, med. gray N5	239
1146.4	1147.4	1.0	silty mudstone, med. gray N5	
1147.4	1148.1	0.7	sandy mudstone, med. gray N5	
1148.1	1149.3	1.2	silty mudstone, med. gray N5	
1149.3	1152.3	3.0	mudstone, lignitic	240
1152.3	1152.7	0.4	claystone, med. dark. gray N4	
1152.7	1155.5	2.8	silty mudstone, medium dark gray N4, slickensides, fines up, laminated, scant organic matter	241
1155.5	1156.9	1.4	silty mudstone, medium gray N5, horizontally laminated with light gray N7, some disturbed laminations, indurated, very silty, some very fine laminations	
1156.9	1157.4	0.5	silty mudstone, dark gray N3, organic material throughout, vaguely laminated, slightly silty, slickensides	
1157.4	1158.3	0.9	silty mudstone, grayish black N2, very faint lamination, fining up	242
1158.3	1159.2	0.9	siltstone, grayish black N2, a few small lenses of black carbonaceous material	
1159.2	1159.6	0.4	sandy mudstone, dark greenish gray 5G, very fine sand with quartz and biotite grains	
1159.6	1160.1	0.5	silty mudstone, dark gray N3	
1160.1	1160.2	0.1	siltstone, medium dark gray N4, mottled	
1160.2	1160.6	0.4	silty mudstone, dark gray N3	
1160.6	1161.0	0.4	siltstone, dark greenish gray 5G, finely laminated	
1161	1161.1	0.1	sandy mudstone, brownish gray 5YR	
1161.1	1161.3	0.2	siltstone, dark greenish gray 5G, finely laminated	
1161.3	1163.3	2.0	siltstone, medium dark gray N4, laminated with darker material, some organics with larger reworked clay clasts	243
1163.3	1165.7	2.4	sandstone, medium light gray N6, very fine grained, fining upwards, sharp contact, quartz and mica rich, subrounded, finely laminated	
1165.7	1170.8	5.1	sandstone, medium gray N5, medium grained, grading into sandy mudstone, quartz rich with some biotite and feldspar	244
1170.8	1175.8	5.0	sandstone, medium light gray N6, medium-fine grained, quartz and mica rich, rounded, coarsening upwards, poorly sorted, black organic laminations, large burrow located between 1171-1172	245
1180.8	1185.8	5.0	sandstone, medium bluish gray 5B 5/1, fine-medium grained, quartz rich, rounded grains, well sorted, massive, thin organics	247
1185.8	1192.3	6.5	sandstone, medium light gray N6, fine grained, quartz rich with dark, non-micaceous grains, subangular-subrounded, massive, moderately well sorted	248
1192.3	1195.0	2.7	sandy mudstone, medium light gray N6 with medium dark gray N4 clay bands, fine sandstone, micaceous, quartz, 1192.3-1193 finely laminated alternately lighter and darker sands	

1195	1198.6	3.6	sandstone, interlaminated dark gray N3 muddy sandstone and medium light gray N6 sandstone, fining upwards from fine sand to greater proportion of silt/mud, moderately well sorted, quartz, rounded grains, evidence of laminations, burrow and soft sediment deformation	250
1198.6	1199.7	1.1	sandstone, medium gray N5, fining upwards, quartz, some mica and hornblende, rounded grains, well sorted, massive, indurated	
1199.7	1200.6	0.9	sandstone, medium gray N5, fining upwards, quartz, rounded grains, well sorted, some laminations and low-angle crossbeds	251
1200.6	1200.8	0.2	core lost	
1200.8	1202.6	1.8	sandstone, grayish blue green 5BG 5/2 at base grading to medium light gray N6 at top of unit, fining upwards from coarse to medium sands, arkosic with lots of quartz and kaolinitized feldspars, rounded grains, well sorted, 30-45 degree crossbeds	
1202.6	1205.0	2.4	sandy mudstone, dark gray N3 silty mudstone and light gray N7 sandy mudstone, poorly developed interbeds between two lithologies in basal portion of unit, sandy mudstone exists as 40mm blebs, moderately well sorted, some thin fine sand laminations, slickensides	
1205	1209.2	4.2	muddy sandstone, muddy, fine grained, quartz, micaceous, subangular, light gray N7 to medium light gray N6, occasional granule-sized claystone clasts, band of 2mm long dark organic flecks and stringers between 1205.5-1205.8	252
1209.2	1213.0	3.8	silty mudstone, medium bluish gray 5B 5/1, moderately well sorted, some thin laminations, finer material infills, root traces or burrows	253
1213	1214.2	1.2	silty mudstone, medium gray N5, fining upwards, moderately well sorted, thin laminations	
1214.2	1218.0	3.8	sandstone, very fine grained, dark greenish gray 5GY 4/1, with minor amounts of mica and dark, non-micaceous minerals, subrounded to subangular, moderately well sorted, dark mineral concentrations along planar to high angle crossbeds	254
1218	1218.5	0.5	silty mudstone, dark gray N3, fining upwards, moderately well sorted, organic fragments (20 mm), possible burrows	255
1218.5	1219.1	0.6	muddy sandstone, dark greenish gray 5G 4/1, moderately well sorted, fine quartz and low angle crossbeds	
1219.1	1219.6	0.5	core lost	
1219.6	1220.4	0.8	sandy mudstone, medium light gray N6, moderately well sorted, fine sand and silt, 1219.8 soft sediment deformation features, indurated, some mudstone blebs	
1220.4	1223.0	2.6	silty mudstone, medium gray N5, fining upwards, well sorted, thin laminations in lower 2" of unit, slickensides	
1223	1225.4	2.4	silty mudstone, dark gray N3 to medium dark gray N4, fining upwards, moderately well sorted, woody material, slickensides	256
1225.4	1226.4	1.0	sandy mudstone, light bluish gray 5B7/1, massive, small burrows, fining upwards from fine sand to silt, moderately well sorted	
1226.4	1227.8	1.4	sandy mudstone, medium dark gray N4, mottled appearance, poorly developed interbeds, some blocky fracture	

1227.8	1228.0	0.2	muddy sandstone, muddy, silty, very fine grained, dark greenish gray 5G4/1, less well cemented between 1227.8 and 1228 than below	257
1228	1229.4	1.4	muddy sandstone. dark greenish gray 5G 4/1, very fine sandy mudstone, interspersed with muddy, silty fine grained sandstone	
1229.4	1230.0	0.6	core lost	
1230	1232.0	2.0	silty mudstone, dark.. greenish gray 5G 4/1	258
1232	1232.6	0.6	sandstone, med. dark. gray N4, fine-grained, poorly sorted, arkosic, massive	
1232.6	1233.6	1.0	silty mudstone, dark gray N3, laminated at top, convolute at base	
1233.6	1235.0	1.4	muddy sandstone, very fine-grained, dark. gray N3, poorly sorted, massive	
1235	1235.4	0.4	sandstone, grayish green 10G 4/2	259
1235.4	1235.9	0.5	silty mudstone, lt. bluish gray 5B 4/2, poorly sorted, rooted	
1235.9	1237.0	1.1	muddy sandstone, med. gray N5, fine-grained, rounded-sub-rounded, arkosic, rooted, massive	
1237	1238.8	1.8	silty mudstone, medium gray N5, coarsening upwards, burrows, thin layers of carbonaceous mudstone	
1238.8	1239.4	0.6	muddy sandstone, med. gray N5, very fine-grained, poorly sorted, subangular, arkosic, rooted, massive	
1239.4	1240.0	0.6	silty mudstone, med. bluish gray 5B 5/1, wavy bedding	
1240	1241.2	1.2	muddy sandstone, med. gray N5, very fine-grained, poorly sorted	260
1241.2	1243.3	2.1	silty mudstone, med. gray N5, prominent burrows between 1242.0 and 1242.8, wavy bedding at base	
1243.3	1243.5	0.2	muddy sandstone, med. gray N5, very fine-grained, poorly sorted	
1243.5	1244.7	1.2	siltstone, med. gray N5 to lt. brownish gray 5YR 6/1, convolute bedding	
1244.7	1245.0	0.3	core lost	
1245	1245.7	0.7	sandy mudstone, dusky green 5G 3/2, very fine	261
1245.7	1245.8	0.1	muddy sandstone, med. dark. gray N4, v. fine-grained	
1245.8	1246.1	0.3	silty mudstone, very light gray N8 and med. gray N5	
1246.1	1246.5	0.4	muddy sandstone, med. dark. gray N4, v. fine-grained	
1246.5	1247.5	1.0	silty mudstone, very light gray N8 and med. gray N5	
1247.5	1248.2	0.7	muddy sandstone, med. dark. gray N4, v. fine-grained, disturbed bedding	
1248.2	1248.4	0.2	silty mudstone, very light gray N8 and med. gray N5	
1248.4	1249.0	0.6	muddy sandstone, med. dark. gray N4, v. fine-grained, disturbed bedding	
1249	1249.2	0.2	silty mudstone, very light gray N8 and med. gray N5	
1249.2	1250.0	0.8	core lost	
1250	1250.2	0.2	muddy sandstone, very fine grained sand	262
1250.2	1251.9	1.7	silty mudstone, med. dark. gray N4, finely bedded at top	
1251.9	1252.8	0.9	claystone, dark.. gray N3, massive	

1252.8	1257.4	4.6	silty mudstone, med. gray N5	263
1257.4	1257.5	0.1	muddy sandstone, med. gray N5, very fine grained, poorly sorted, subangular, massive	
1257.5	1262.1	4.6	silty mudstone, med. gray N5 to dark gray N3, some slickensides	264
1262.1	1263.2	1.1	sandstone, very fine grained, quartz	
1263.2	1271.6	8.4	silty mudstone, med. gray N5 with light gray N7 laminations, soft sediment deformation, some slickensides, convolute at 1265, 1269, and 1271 feet	265-266
1271.6	1271.8	0.2	muddy sandstone, very fine grained, quartz, finely laminated	267
1271.8	1272.7	0.9	silty mudstone, med. gray N5	
1272.7	1273.8	1.1	muddy sandstone, very fine grained, quartz, finely laminated	
1273.8	1274.6	0.8	silty mudstone, med. gray N5	
1274.6	1275.1	0.5	muddy sandstone, very fine grained, quartz, finely laminated	
1275.1	1277.0	1.9	muddy sandstone, light olive gray 5Y 6/1 sandstone alternating with layers of siltstone in horizontal and convoluted layers at 1275.7	
1277	1277.1	0.1	sandstone, clay intraclasts	
1277.1	1282.1	5.0	sandstone, greenish gray 5G 6/1 medium to fine-grained quartz, moderately well-sorted, fining upwards, large clay blebs at top, intraclasts	268
1282.1	1287.2	5.1	sandstone, lt. bluish gray 5B 7/1, fine-grained, subangular to subrounded, moderately well-sorted, kaolinitized feldspars, arkosic	269
1287.2	1287.8	0.6	muddy sandstone, med. bluish gray 5B 5/1, fine-medium grained arkosic, mod. well-sorted, fining upwards, with bands of dark organics and green clays	270
1287.8	1288.2	0.4	muddy sandstone, dusky green 5G 3/2, coarse sand in muddy matrix, white N9, moderate reddish orange 10R 6/6, clay pebble clasts	
1288.2	1288.6	0.4	muddy sandstone, coarse sand in muddy matrix	
1288.6	1289.0	0.4	muddy sandstone, coarse to very coarse sand in muddy matrix, clay pebble clasts, bimodal sorting	
1289	1293.6	4.6	muddy sandstone, grayish green 10GY 5/2, medium-coarse sand in muddy matrix, occasional. rip-ups,	271
1293.6	1293.9	0.3	sandstone, lt. bluish gray 5B7/1, medium-grained arkosic, quartz	
1293.9	1294.7	0.8	muddy sandstone, lt. bluish gray 5B7/1, fine-grained arkosic, fining upwards	
1294.7	1295.1	0.4	muddy sandstone, coarse grained sand and pebble-sized clay clasts	
1295.1	1296.1	1.0	drilling mud	
1296.1	1297.5	1.4	silty mudstone, N6 to N4, some slickensides	272
1297.5	1299.9	2.4	siltstone, zones of fine laminations and disturbed zones	
1299.9	1301.1	1.2	silty mudstone, mottled lt. gray N7 to med. dark. gray N4, minor slickensides	
1301.1	1302.0	0.9	silty mudstone, medium gray N5 to medium dark gray N4, very fine sand	273
1302	1303.6	1.6	silty mudstone, medium gray N5 to medium dark gray N4, slickensides	

1303.6	1304.1	0.5	core lost	
1304.1	1304.9	0.8	sandstone, dark gray N3, v fine sand	274
1304.9	1306.6	1.7	sandy mudstone, medium gray N5 to medium dark gray N4, with occasional light gray N6 blotches, fine sand, feldspar grains	
1306.6	1309.1	2.5	silty mudstone, medium gray N5, medium light gray N6, with light gray N7 blotching, very fine sand	
1309.1	1312.0	2.9	sandy mudstone, laminated dark gray N3 medium light gray N6 with gradational contacts, mod well sorted, some blebs, fine sand, rounded, quartz, thin laminations, soft sediment deformation	275
1312	1313.4	1.4	silty mudstone, medium light gray N6, horizontal laminations, some slickensides	276
1313.4	1314.9	1.5	siltstone, olive gray 5Y 4/1	
1314.9	1316.0	1.1	sandy mudstone, very fine sand, organics, bedding disturbed by roots or bioturbation, slickensides	
1316	1319.5	3.5	drilling mud	277
1319.5	1319.8	0.3	core lost	
1319.8	1320.4	0.6	siltstone, dark greenish-gray 5G 4/1,	
1320.4	1323.3	2.9	sandy mudstone, medium dark gray N4, fine laminae, disturbed inclined ripples and crossbeds	278
1323.3	1328.5	5.2	silty mudstone, greenish black 5GY 2/1, fine laminations	279
1328.5	1332.5	4.0	muddy sandstone, very light gray N8, fine to medium sand, fining upwards, organic matter disturbing bedding, occasional silty layers, intraclasts	280
1332.5	1332.7	0.2	sandy mudstone, medium gray N5, fine to medium sand	
1332.7	1332.9	0.2	muddy sandstone, very light gray N8, fine to medium sand, fining upwards, organic matter disturbing bedding, occasional silty layers, intraclasts	
1332.9	1333.4	0.5	sandy mudstone, medium gray N5, fine to medium sand	
1333.4	1333.5	0.1	core lost	
1333.5	1334.5	1.0	siltstone, fine laminae, bioturbated, fining upwards sequence	281
1334.5	1335.8	1.3	sandy mudstone, light gray N7, fining upwards sequence	
1335.8	1338.0	2.2	muddy sandstone, medium gray N3, fining upwards sequence, medium sand laminae	
1338	1338.5	0.5	silty mudstone	
1338.5	1339.7	1.2	core lost	
1339.7	1340.4	0.7	siltstone, dark gray N3	282
1340.4	1342.3	1.9	sandy mudstone, dark greenish gray 5G 4/1, occasional fine root traces, massive, fine sand, mica	
1342.3	1343.0	0.7	siltstone, greenish black 5G 2/1	
1343	1343.9	0.9	claystone, olive gray 5Y 4/1	
1343.9	1345.0	1.1	siltstone, dark greenish gray 5GY 4/1, disturbed fine laminae	
1345	1349.0	4.0	muddy sandstone, light olive gray 5Y 6/1, fine sand with silt laminations, wavy bedding, some horizontal and angular beds, heavy mineral streaks form bedding lines, slightly micaceous, intraclasts	283
1349	1349.3	0.3	core lost	

1349.3	1351.2	1.9	siltstone, greenish black 5G 2/1, fine horizontal laminae with organic matter up to one inch, cross-bedded	284
1351.2	1351.3	0.1	sandy mudstone, greenish gray	
1351.3	1353.3	2.0	sandy mudstone, fining upwards sequence, medium dark gray N4, slightly micaceous, slickensides	
1353.3	1355.3	2.0	sandy mudstone, medium light gray N6 to medium dark gray N4, very fine sand, some horizontal silt bands, micaceous quartz, organics, large clay intraclast	285
1355.3	1356.1	0.8	claystone, dark gray N3, extensive slickensides	286
1356.1	1359.9	3.8	silty mudstone, dark greenish gray 5GY 4/1to medium bluish gray 5B 5/1, micaceous layers, organic rich layers with roots, burrows, intraclasts, extremely fine laminae in places	
1359.9	1362.1	2.2	silty mudstone, medium gray N5, fining upwards, fine sand laminations, slightly micaceous, kaolinitized feldspars, organics	287
1362.1	1363.0	0.9	silty mudstone, slickensides	
1363	1365.0	2.0	silty mudstone, medium dark gray N4, coarsens upwards, organic material	
1365	1366.8	1.8	silty mudstone, medium gray N5, no laminations, siltier downward, few areas with wavy laminations	288
1366.8	1369.6	2.8	silty mudstone, grayish black N2 and medium gray N5, fine laminations (1mm), bioturbated	
1369.6	1369.8	0.2	core lost	
1369.8	1370.1	0.3	silty mudstone, medium dark gray N4	
1370.1	1370.2	0.1	silty mudstone	
1370.2	1372.0	1.8	muddy sandstone, fining up , medium light gray N6, organic rootlets in top half, clay clasts to 10mm	
1372	1372.9	0.9	muddy sandstone, med. dark gray N4, fine grained,	
1372.9	1373.4	0.5	muddy sandstone, wavy laminations	
1373.4	1375.2	1.8	silty mudstone, grayish black N2, slightly silty, uniform layer, slickensides	290
1375.2	1377.0	1.8	sandy mudstone, dark gray N3, slightly silty, some bioturbation, slickensides, some patches of silty mudstone, fining up	
1377	1377.5	0.5	silty mudstone, medium gray N5, some fine sands, slight bioturbation	
1377.5	1380.4	2.9	silty mudstone, dark gray N3, uniform, some very fine sand, mostly silty, slickensides, fining upward, possible burrows	291
1380.4	1381.8	1.4	sandy mudstone, brownish black 5YR 2/1, organic matter throughout, fine sand grains and silt present, angular quartz and some gypsum crystals present	
1381.8	1383.2	1.4	silty mudstone, dark gray N3, micaceous	292
1383.2	1383.9	0.7	silty mudstone, medium gray N5-medium dark gray N4, micaceous, kaolinite and gypsum crystals, slickensides	
1383.9	1384.5	0.6	drilling mud	293
1384.5	1385.1	0.6	sandy mudstone, dark gray N3, fine grained sand within mudstone, small whitish specks	

1385.1	1386.1	1.0	sandy mudstone, light olive gray 5Y5/2, fine grain sand throughout, very small kaolinite specks, muscovite rich, some organics	
1386.1	1389.1	3.0	sandstone, medium gray N5, fine grained, very micaceous, quartz, massively bedded, fining upward from medium to fine	
1389.1	1394.0	4.9	sandstone, variable dark gray N3 - medium light gray N6, massively bedded, fining upwards, biotite and organic crossbedding at basal end	294
1394	1395.7	1.7	sandstone, medium light gray, N6, medium grains, fining upwards, very micaceous and quartz rich, some hornblende, subrounded grains, well sorted, massive	295
1395.7	1397.7	2.0	core lost	
1397.7	1399.0	1.3	silty mudstone, medium dark gray N4, well sorted, massive, slickensides	
1399	1401.0	2.0	silty mudstone, dark gray N3, very fine sand and silt, with faint greenish tinge, quartz and mica flecks	296
1401	1401.4	0.4	sandy mudstone, muddy silty, very fine sand, with thin interbeds of darker, finer grained sediments, crossbedding, mica flecks	
1401.4	1401.5	0.1	silty mudstone, dark gray N3 or medium dark gray N4	
1401.5	1406.1	4.6	silty mudstone, dark gray N3, well sorted, one fine grained sandstone patch at 1401.9-1402.0, blocky fracture, massive	297
1406.1	1410.6	4.5	silty mudstone, medium light gray N6 to medium dark gray N4, abundant tiny flecks of darker muddy sediments, at 1406.7 coarse-grained sand with amber clast	298
1410.6	1413.9	3.3	silty mudstone, dark gray N5-light gray N7, mottled, moderately well sorted	299
1413.9	1415.0	1.1	sandy mudstone, greenish gray 5G6/1 moderately well sorted, fine sand and mud, thin laminations	
1415	1415.6	0.6	silty mudstone, dark gray N3, silty mudstone, moderately well sorted, massive	
1415.6	1417.3	1.7	silty mudstone, grayish black N2	300
1417.3	1418.1	0.8	sandy mudstone, dark gray N3-light gray N7, fine sandy mudstone, blotchy, some thin organic strands	
1418.1	1419.6	1.5	silty mudstone, very light gray N8 to bluish white 5B9/1, occasional dark organic stringers up to 18mm in length	
1419.6	1420.1	0.5	core lost	
1420.1	1424.1	4.0	sandstone, olive gray 4/1, fissile, quartz, very fine sand, some thin elongated clay clasts floating throughout, one burrow	301
1424.1	1424.6	0.5	core lost	
1424.6	1424.8	0.2	drilling mud	
1424.8	1426.0	1.2	silty mudstone, med. dark. gray N4 silty mudstone interlaminated with very fine sandy mudstone, pale orange 10YR 7/4. soft sediment deformation, slightly micaceous	302
1426	1428.8	2.8	silty mudstone, brownish black 5YR 2/1 silty mudstone, very common thin lenses of floating lignite black N1, some larger coalified branch fragments	
1428.8	1429.4	0.6	core lost	

1429.4 1433.5 4.1	silty mudstone, med. light gray N6 silty mudstone, moderately well sorted, laminae at base of unit, abundant organic fragments- leaves and root traces, bioturbation	303
1433.5 1434.3 0.8	silty mudstone, dark. gray N3 silty mudstone, moderately well sorted, thin wavy laminae with organic fragments on bedding planes	
1434.3 1439.1 4.8	silty mudstone, dark greenish gray 5G 4/1, root trace at 1436, 1437.0-14.38.3 multiple episodes of soft sediment deformation, 1437.9-1437.7 rip up clasts	304
1439.1 1439.5 0.4	core lost	
1439.5 1441.6 2.1	silty mudstone, dark gray N3, fining upwards	305
1441.6 1442.3 0.7	muddy sandstone, dark greenish gray 5G 4/1, medium grained sands in muddy matrix with thin organic seams, grayish green 10G 4/2 and dark yellowish brown 10YR 5/4 clay intraclasts , very micaceous, angular grains	
1442.3 1449.1 6.8	core lost	
1449.1 1452.8 3.7	sandy mudstone, greenish gray 5G 6/1 mudstone with fine-very fine grained sands, areas with bedded grayish green 10G 4/2 clay intraclasts up to 3cm in length, some clay and sand laminations, disrupted fabric, bioturbation	306
1452.8 1456.2 3.4	muddy sandstone, grayish green 5G 5/2 fine to very fine grained sand, fining upwards, quartz with small clay blebs (~3mm) throughout, some darker clay crossbeds, indurated, 1455.8 Red grains appear in coarser sand at base	307
1456.2 1460.2 4.0	muddy sandstone, medium bluish gray 5B 5/1, medium grained, quartz, few feldspars, red rock fragments throughout, rounded grains, organics	308
1460.2 1463.6 3.4	muddy sandstone, dark yellow green 5GY 5/2 to grayish olive green 5GY 3/2 muddy sandstone with disrupted fabric, floating clasts of coal, silt, and mud, slickensides	309
1463.6 1463.8 0.2	lignite	
1463.8 1465.0 1.2	core lost	
1465 1465.6 0.6	sandy mudstone, gray 5G 4/1 sandy mudstone	310
1465.6 1467.4 1.8	sandstone, light gray sandstone with thin distorted flaser beds, organics and isolated floating blebs of green 5B 5/1 mudstone	
1467.4 1470.5 3.1	muddy sandstone, medium bluish gray 5B 5/1 fine grained sandstone, quartz	311
1470.5 1474.2 3.7	core lost	
1474.2 1479.2 5.0	muddy sandstone, medium bluish gray 5B 5/1 fine grained sandstone, subangular-subrounded grains, quartz, fining upwards, clay clasts up to 10cm, fracturing filled with calcite	312
1479.2 1483.4 4.2	muddy sandstone, medium gray N5 medium grained muddy sandstone, massive, fining upwards, some clay clasts and organics	313
1483.4 1484.1 0.8	muddy sandstone, horizontal bedding, coarse grained, quartz, red sandstone grains, some feldspars	314

1484.1	1486.2	2.1	muddy sandstone, medium gray N5, medium-fine grained, subangular, quartz and mica, red sand grains,	
1486.2	1488.3	2.1	silty mudstone, dark gray N3, slightly silty, slickensides, core was dropped and spaces incurred.	
1488.3	1492.3	4.0	sandy mudstone, medium gray N5 and dark gray N3, very fine grained sand, bioturbated	315
1492.3	1492.5	0.2	muddy sandstone, medium light gray N6, medium grained, laminated with organics, quartz, also red sand grains, subrounded	
1492.5	1493.7	1.2	sandstone, medium light gray N6 very fine grained, angular crossbeds with organics on bedding planes, red grains	316
1493.7	1495.4	1.7	sandstone, fine-medium grained light gray N6 sandstone with finer grained clasts within	
1495.4	1497.5	2.1	silty mudstone, medium gray to medium dark gray N4-N5 silty mudstone, slickensides	
1497.5	1499.6	2.1	muddy sandstone, medium light gray N6 and dark gray N3 very fine grained sand, mottling, bioturbation	317
1499.6	1500.5	0.9	sandy mudstone, dark gray N3, contains many dusky blue green 5BG 3/2 clay intraclasts, clay and sandstone laminations	
1500.5	1501.0	0.5	sandy mudstone, medium gray N5, fine (1mm) laminations	
1501	1501.5	0.5	sandstone, dark gray N3, pebble-sized clay intraclasts	
1501.5	1501.7	0.2	muddy sandstone, medium gray N5, very fine sand	318
1501.7	1501.8	0.1	silty mudstone, medium dark gray N4, slightly silty	
1501.8	1503.5	1.7	sandstone, greenish gray 5G 6/1, medium - coarse sand, muddy matrix, granule sized clay clasts throughout, some organics, poorly sorted, quartz	
1503.5	1506.5	3.0	mudstone, medium gray N5 and light gray N7, soft sediment deformation	
1506.5	1509.2	2.7	silty mudstone, dark gray N3, slightly silty, some areas of soft sediment deformation grading into grayish black	
1509.2	1511.5	2.3	sandy mudstone, medium gray N5, mostly silty, some fine grained sands,	319
1511.5	1511.7	0.2	muddy sandstone, medium gray N5 and light gray N7, areas of bioturbation marbled pattern, slickensides, some clay clasts	
1511.7	1512.3	0.6	drilling mud/clay	320
1512.3	1512.9	0.6	silty mudstone, grayish black N2, light gray N7 clast, slightly silty	
1512.9	1513.4	0.5	sandy mudstone, medium dark gray N4 - medium light gray N6 sandy mudstone, bioturbated	
1513.4	1514.4	1.0	drilling mud/clay	
1514.4	1518.5	4.1	sandy mudstone, medium dark gray N4 silty - medium light gray N6 sandy mudstone, ripple marks and fine laminations	321
1518.5	1519.8	1.3	sandy mudstone, fine sand size, quartz, moderately well sorted, thin laminations, low angle beds	322
1519.8	1520.1	0.3	silty mudstone, dark gray N3, silty mudstone, moderately well sorted, massive	
1520.1	1522.1	2.0	sandy mudstone, medium light gray N6, fine sand size, moderately	

			well sorted, laminations,	
1522.1	1523.5	1.4	core lost	
1523.5	1524.6	1.1	silty mudstone, medium light gray N6, very fine sand, some coarse areas	323
1524.6	1528.0	3.4	muddy sandstone, greenish-gray 5G 6/1, fine sand, fine laminations with organic material on the bedding planes, finer grained blebs	
1528	1533.9	5.8	sandstone, medium light gray N6, very coarse sandstone fining upwards to a fine-grained muddy sandstone, quartz composition, subrounded grains, moderately well sorted, thin laminations with organics occurring on bedding planes,some oxidation	324-325
1533.9	1534.3	0.4	sandstone, poorly sorted, grayish blue green 5BG 5/2, medium sand of 20 mm, angular to rounded, mostly quartz, red grains	
1534.3	1538.7	4.4	silty mudstone, medium dark gray N5, amber 1 piece, slickensides throughout, bioturbated, leaf impression at 1538.5	326
1538.7	1539.5	0.8	gravelly mudstone, grayish blue-green 5BG 5/2 from fine sand to pebbles	327
1539.5	1543.4	3.9	silty mudstone, medium light gray N6, bioturbated, organics throughout	
1543.4	1545.6	2.2	sandstone, medium light gray N6 at top to very light gray N8 at base, fining upwards sequence from coarse sand to fine sand, sand color mud dusky blue green 5BG 3/2, organics N1, sand poorly sorted, rounded to subrounded, organics and mudstones form laminations	328
1545.6	1546.2	0.6	sandstone, very light gray N8, coarse sand, mod well sorted, subrounded, quartz, thin mud layers, dusky blue green 5BG 3/2, organics	329
1546.2	1547.2	1.0	sandstone, medium gray N5 to v light gray N8 to black N1, medium sand, well sorted, subrounded, quartz, organics form lineations and bedding planes, heavily bioturbated	
1547.2	1548.0	0.8	sandstone, medium gray N5 to v light gray N8 to black N1, fine sand, medium sand, well sorted, subrounded, quartz, organics form lineations and bedding planes, heavily bioturbated, very light gray N8	
1548	1550.3	2.3	sandstone, medium gray N5 to light gray N7 and black N1, very fine sand, quartz, mod well sorted, subrounded and subangular, micaceous , heavily bioturbated at 1548.2, cross beds, thin laminae	
1550.3	1552.0	1.7	silty mudstone, medium gray N5 to medium light gray N6, heavily disturbed bedding, fine sand pockets, slickensides	
1552	1553.3	1.3	sandstone, light brownish gray , 5YR 6/1, fine sand, well sorted, rounded, quartz, low angle bedding, 1552.7 - 1553.3	331
1553.3	1553.7	0.4	sandstone, light gray N6 to v light gray N8, medium sand, rounded, poorly sorted	
1553.7	1553.9	0.2	sandstone, light brownish gray 5YR 6/1, coarse sand, rounded, mod well sorted, cross bedded	
1553.9	1555.1	1.2	sandstone, light gray N6 to v light gray N8, medium sand, rounded, lignite layers/clasts, poorly sorted	
1555.1	1557.5	2.4	sandstone, medium light gray N6 to v light gray N8, fine sand, poorly	

			sorted, angular to subangular, fining upwards sequence, organics, mud intraclasts	332
1557.5	1558.0	0.5	sandstone, medium light gray N6, medium sand, poorly sorted, angular to subangular, laminae of organics	
1558	1559.1	1.1	sandstone, greenish gray 5GY 6/1 and bluish white 5B 9/1, very fine sand, fine laminations, organics on bedding planes	333
1559.1	1559.6	0.5	sandstone, bluish white 5B 9/1 and medium light gray N6, medium – coarse sand, arkosic with kaolinite, some black clay clasts (3cm) contains black chert, poorly sorted	
1559.6	1560.3	0.7	silty mudstone, medium gray N5, disturbed laminations, bioturbation,	
1560.3	1561.0	0.7	sandstone, bluish white 5B 9/1 and medium light gray N6, very coarse sand, quartz, arkosic, floating green and gray clay clasts, some red granules, angular, poorly sorted with large black clay clasts on interior surfaces, slickensides, chert	
1561	1565.0	4.0	sandstone, coarse grained, poorly sorted, angular, quartz and arkosic, kaolinitization of feldspars, intraclasts, organics, concretion with abundant pyrite within and surrounding edges, poorly consolidated	334-335
1565	1566.5	1.5	sandy mudstone, dark gray N3 to medium light gray N6, horizontal bedding - wavy and bioturbated, burrows filled with very fine sand, small clay intraclasts	
1566.5	1566.6	0.1	silty mudstone, medium dark gray N4	336
1566.6	1568.3	1.7	mudstone, grayish black N2, slickensides	
1568.3	1571.7	3.4	muddy sandstone, medium light gray N6 to medium gray N5 with medium dark gray N4 bits of organic material, very fine grained, organic content decreases upward, also contains sparse granules of claystone, amber, charcoal	
1571.7	1573.3	1.6	silty mudstone, med. dark. gray N4 silty mudstone with two light gray N7 sandy mudstone interbeds, moderately well sorted, massive with few thin fine sand laminations, scattered organics, slickensides	337
1573.3	1573.5	0.2	sandy mudstone, light gray N7 sandy mudstone interbedded, moderately well sorted very fine sand and mud, thin sandy laminations	
1573.5	1576.7	3.2	silty mudstone unit same as 1571.7-1573.3'	
1576.7	1579.4	2.7	silty mudstone, med. dark. gray N4 silty mudstone, may be fining upwards, well sorted, massive with exception of thin silty lenses, blocky fracture, possible organic-rich mudstone at base of unit	338
1579.4	1580.3	0.9	silty mudstone, med. gray N5 silty mudstone, massive, moderately well sorted, fine-grained blebs and organic fragments	
1580.3	1580.5	0.2	silty mudstone, med. dark. gray N4 silty mudstone, well sorted massive unit	
1580.5	1582.3	1.8	silty mudstone, med. dark. gray N4 silty mudstone, well sorted, massive	339
1582.3	1584.2	1.9	sandy mudstone, greenish gray 5G 6/1 sandy mudstone, fine	

			sand, mud and silt, fining upwards, quartz and mica, subrounded grains, moderately well sorted, low angle crossbeds and laminations, mudstone rip-ups up to 50mm in length, burrowed	
1584.2	1584.3	0.1	drilling mud	
1584.3	1589.3	5.0	sandy mudstone, med. bluish gray 5B 5/1 sandy mudstone fining upwards from medium to fine sand, mostly quartz with some mica present, moderately well sorted, subrounded grains, cross-bedded and laminated with woody material.	340
1589.3	1590.5	1.2	sandy mudstone, med. gray N5 sandy mudstone interbedded with medium-fine sand and silt, crossbedding throughout, moderately well sorted with subrounded grains.	341
1590.5	1593.5	3.0	silty mudstone, med. dark gray N4 silty mudstone, well sorted with thin laminations in places, mostly massive with organic fragments throughout	
1593.5	1597.0	3.5	silty mudstone, dark gray N3 silty mudstone, well sorted, massive with laminations in lower 0.3 of core, small organic fragments scattered throughout	342
1597	1602.2	5.2	silty mudstone, dark. grayN3 silty mudstone, massive with slickensides on exposed surfaces, coarsens in middle of unit	343
1602.2	1603.4	1.2	mudstone, dark. gray N3 carbonaceous mudstone with some clay	344
1603.4	1604.1	0.7	claystone, dark. gray N3 claystone.	
1604.1	1604.6	0.5	silty mudstone, dark. gray N3 silty mudstone	
1604.6	1605.1	0.5	claystone, dark. gray N3 claystone.	
1605.1	1605.8	0.7	silty mudstone, dark. gray N3 silty mudstone	
1605.8	1607.1	1.3	silty mudstone, dark. gray N3 silty mudstone alternating with N5 siltstone	
1607.1	1607.5	0.4	sandstone, med. dark. gray N4 very fine sandstone	
1607.5	1608.0	0.5	muddy sandstone, very light gray N8 muddy sandstone with intraclasts of N5 mudstone and bioturbation	345
1608	1612.3	4.3	sandstone, med. gray N5 sandstone. Well developed fining upward sequence with granules at the bottom, massive with quartz, arkosic well sorted, subrounded grains.	
1612.3	1612.5	0.2	sandstone, med. gray N5 medium sandstone with subrounded grains, some clay clasts.	346
1612.5	1613.1	0.6	sandstone, dusky blue 5BG 3/2, very coarse sand, organic fragments, 1612.75' darker siltstone lens	
1613.1	1613.3	0.2	siltstone, med. dark gray N3 siltstone	
1613.3	1613.5	0.2	sandy mudstone, med. dark. gray N3 siltstone with embedded very coarse sand	
1613.5	1614.9	1.4	sandstone, finely laminated near horizontal beds, fine to very fine sand, predominantly med. dark. gray N3 with some bluish, greenish, brown and tan layers at top, lower laminae below 1614.0 all gray, 30% quartz, some organic fragments	
1614.9	1616.4	1.5	sandstone, fine to very fine medium light gray N6 to medium	

			gray (N5) sandstone, laminations, 1615.6' silty mudstone layer, 1616.2 1616.4 larger dark. gray siltstone laminae	
1616.4	1616.6	0.2	sandstone, medium gray, coarsening downward	
1616.6	1616.8	0.2	sandstone, dark. gray N2 medium to coarse mottled sandstone	347
1616.8	1617.4	0.6	sandstone, medium gray N5 very fine grained sandstone with fine laminations, organic material along bedding planes.	
1617.4	1621.6	4.2	sandstone, medium gray N5 medium grained sandstone with organic material spread throughout, quartz and feldspar grains, alternating bands of coarser material	
1621.6	1626.7	5.1	sandstone, medium gray N5 coarse grained sandstone with mottles and clasts up to 6mm. Faint bedding, composed of quartz, feldspar, poorly sorted	348
1626.7	1628.8	2.1	sandstone, greenish gray 5G 6/1 to white N9 gravelly sandstone composed of quartz, arkosic material, pebble sized dusky blue green 5BG 3/2 clay clasts, feldspars weathering to kaolinite, poorly sorted, massive	349
1628.8	1630.1	1.3	muddy sandstone, greenish gray 5G 6/1 fine to medium grained sandstone with muddy matrix, poorly sorted, composed of quartz, arkose, kaolinitized grains, vague x-bedding, subangular grains, gradational contact with above.	
1630.1	1630.8	0.7	muddy sandstone, greenish gray 5G 6/1 medium to coarse grained sandstone with muddy matrix composed of arkose, quartz grains with clay clasts	
1630.8	1631.3	0.5	muddy sandstone, greenish gray 5G 6/1 medium to very coarse sandstone with muddy matrix, composed of arkose, quartz, clasts of clay and kaolinite, very poorly sorted , angular grains	
1631.3	1633.1	1.8	muddy sandstone, greenish gray 5G 6/1 fine to medium grained sandstone with muddy matrix composed of arkose, quartz, subangular grains, massive, fining upwards	350
1633.1	1637.0	3.9	muddy conglomerate, dusky blue green 5BG 3/2 muddy conglomerate with cobble sized gray clay clasts, arkosic pebbles, black chert and quartz pebbles with dark gray clay clasts, entire tube has calcareous matrix, poorly sorted, rounded to subrounded grains, fining upwards	351
1637	1638.0	1.0	sandy mudstone, med. dark gray N4 to N7 mottled sandy mudstone with bioturbation, sharp contact with above.	
1638	1638.2	0.2	core lost	
1638.2	1638.5	0.3	sandy mudstone, med. dark gray N4 to N7 mottled sandy mudstone with bioturbation	
1638.5	1640.5	2.0	silty mudstone, light gray N7 to N3 silty mudstone with fine laminations, organic material on bedding planes, x-bedded laminations, and some very fine sand.	
1640.5	1640.9	0.4	silty mudstone, bluish white 5B 9/1 and grayish black N2 silty mudstone with very fine laminations, organic material along bedding planes, calcareous matrix, slight x-bedding.	

1640.9	1641.3	0.4	muddy sandstone, dusky blue green 5G 3/2 muddy sandstone with arkose and quartz, poorly sorted, very coarse grained, coarsening upwards, subrounded with some clay clasts.	
1641.3	1642.4	1.1	muddy sandstone, greenish gray 5G 6/1 and bluish white 5B 9/1 fine grained sandstone in muddy matrix composed of quartz, arkose, gray clay clasts, vague x-bedding with organic material, coarsens upwards	352
1642.4	1646.5	4.1	sandy mudstone, greenish gray 5G 6/1 to medium bluish gray 5B 5/1 mottled sandy mudstone with quartz, subrounded grains, slickensides	
1646.5	1646.8	0.3	silty mudstone, dusky blue green 5BG 3/2 silty mudstone	353
1646.8	1647.7	0.9	gravelly sandstone, dusky blue green 5BG 3/2 and grayish blue green 5BG 5/2 gravelly sandstone with a muddy matrix, grains of arkose, quartz, clay clasts, red granules, poorly sorted, massive,	
1647.7	1648.7	1.0	silty mudstone, greenish gray 5G 6/1 silty mudstone with some very fine grained sands of quartz, mottled and bioturbated	
1648.7	1649.9	1.2	mudstone, medium gray N5 mudstone grading into lignite seams, lots of organic material	
1649.9	1651.0	1.1	silty mudstone, medium gray N5 silty mudstone, poorly consolidated.	
1651	1651.5	0.5	core lost	
1651.5	1653.1	1.6	silty mudstone, medium dark gray N4 silty mudstone, poorly sorted, massive, slickensides, organic material, chippy.	354
1653.1	1654.0	0.9	core lost	
1654	1656.5	2.5	silty mudstone, medium dark gray N4 silty mudstone, poorly sorted, massive, slickensides, organic material, chippy.	355
1656.5	1660.7	4.2	silty mudstone, medium gray N5 slightly silty mudstone with slickensides on exposed surfaces, organic material, some bedding near bottom	356
1660.7	1661.8	1.1	muddy sandstone, grayish blue green 5BG 5/2 fine grained muddy sandstone fining upwards to a silty mudstone, sand fraction is mostly quartz with subrounded grains.	
1661.8	1663.2	1.4	silty mudstone, medium gray N5 silty mudstone coarsening upwards with silty laminae near top, organic fragments and slickensides throughout	
1663.2	1665.0	1.8	silty mudstone, grayish green 10G 4/2 silty mudstone coarsening upwards to silt, moderately well sorted with slickensides.	
1665	1667.9	2.9	silty mudstone, dusky blue green 5BG 3/2 slightly silty mudstone, almost a claystone, organic material throughout	357
1667.9	1668.7	0.8	silty mudstone, light gray N7 to N6 and 5BG 3/2 as above, very fine grained silty mudstone fining upward, well laminated with bioturbation in middle, no bioturbation at top or bottom, blebs of fine material.	
1668.7	1670.0	1.3	claystone, dusky blue green 5G 3/2 claystone, slickensides on exposed surfaces	
1670	1671.2	1.2	sandstone, medium light gray N6 to N5 fine to medium sandstone with organic material throughout, thick fine grained laminae, unit is poorly sorted with quartz and red grains throughout.	358

1671.2	1672.2	1.0	silty mudstone, grayish black N2 silty mudstone with slickensides on exposed surfaces, mostly organic material, massive.	
1672.2	1674.2	2.0	sandy mudstone, light gray N7 to N4 very fine grained sandy mudstone with bioturbation throughout, roots near bottom, fine to medium laminations where not bioturbated.	
1674.2	1675.2	1.0	silty mudstone, dark gray N3, dusky blue green 5BG 3/2 slightly silty mudstone, almost a claystone, with slickensides exposed on surfaces, massive.	359
1675.2	1675.8	0.6	sandstone, medium gray N5 very fine grained sandstone with bioturbation, coarser infills, and faint bedding.	
1675.8	1677.8	2.0	silty mudstone, dark gray N3 to grayish black N2 slightly silty mudstone, slickensides exposed on all surfaces	
1677.8	1680.3	2.5	sandstone, medium light gray N6 very fine grained sandstone with slickensides and organic material, moderately well sorted.	360
1680.3	1682.8	2.5	silty mudstone, light olive gray 5Y 6/1 silty mudstone, poorly laminated, thin calcareous layers N8 to N9 in color, organic material throughout.	361
1682.8	1682.9	0.1	claystone, medium dark gray N4	
1682.9	1684.7	1.8	silty mudstone, light olive gray 5Y 6/1 silty mudstone, poorly laminated, thin calcareous layers, organics.	
1684.7	1687.8	3.1	silty mudstone, medium dark gray N4 silty mudstone, "chippy," organic material throughout.	362
1687.8	1688.0	0.2	mudstone, brownish gray 5YR 2/1 carbonaceous mudstone, lignitic clasts	363
1688	1690.2	2.2	lignite, black N1	
1690.2	1691.6	1.4	silty mudstone, dark greenish gray 5G 4/1 silty mudstone, massive, some organics	
1691.6	1692.8	1.2	sandy mudstone, interlaminated bluish gray 5B 5/1 and light olive gray 5Y 6/1 siltstone and very fine grained sandstones, bioturbated throughout.	
1692.8	1693.0	0.2	sandstone, interlaminated bluish gray 5B 5/1 and light olive gray 5Y 6/1 siltstone and very fine grained sandstones, bioturbated throughout.	364
1693	1697.8	4.8	silty mudstone, medium gray N5 to light brownish gray 5YR 6/1 silty mudstone interlaminated with very fine grained sandstones, well developed bedding and laminations	
1697.8	1699.8	2.0	sandy mudstone, medium gray N5 to N6 very fine grained sand mudstone, ripple laminated, bioturbated, organic material on bedding planes.	365
1699.8	1701.4	1.6	sandy mudstone, dark gray N3 to N5 very fine grained sandy mudstone with alternating bands of bioturbation and laminations.	
1701.4	1702.8	1.4	sandy mudstone, dark gray N3 to N5 very fine grained sandy mudstone with alternating bands of bioturbation and laminations, x-bedding	

1702.8	1704.0	1.2	sandstone, medium gray N5 to medium dark gray N4, interbedded sandstone and silty mudstone, moderately well sorted, subrounded. quartz, very fine sand layers are disturbed probably by soft sediment deformation, some ripple trough fills observed	366
1704	1711.3	7.3	silty mudstone, medium dark gray N4, interbedded with some very fine sandstone, thin laminations and bioturbated throughout, observed ripple marks and/or crossbeds in the sandy units	367
1711.3	1712.5	1.2	sandstone, light gray N4, gradational contact, fine-medium sandstone, moderately well sorted, angular to rounded with slight bedding visible but mostly massive, mostly quartz	368
1712.5	1715.4	2.9	silty mudstone, medium dark gray N4, slightly silty mudstone with several bands of yellowish gray 5Y 8/1 clay and very light gray N8 medium sandstone, some bioturbation, massive lenses which are massive, moderately well sorted, angular to rounded	
1715.4	1716.0	0.6	sandstone, light gray N7, medium grained sandstone, faint bedding, poorly sorted, large pebble-size clay clast near bottom	
1716	1716.7	0.7	silty mudstone, dark gray N3 and light olive gray 5Y 6/1, 0.1' laminations	369
1716.7	1717.6	0.9	sandstone, white N9, very fine grained, calcareous cement, quartz, mottled wavy contacts on both ends	
1717.6	1718.5	0.9	silty mudstone, dark gray N3 silty mudstone, some laminations and floating clasts of grayish orange 10 YR 7/4	
1718.5	1720.3	1.8	sandstone, medium gray N5, coarse to medium grained, coarsening upwards, quartz, angular grains, poorly sorted, gray clay rip-up clasts throughout (1.5 cm), vaguely laminated	
1720.3	1720.9	0.6	sandstone, sharp contact, well rounded very coarse sand, quartz, chert grains, red grains, poorly sorted; this grades into a silty mudstone, dark gray N3 and light olive gray 5Y 6/1	
1720.9	1722.8	1.9	sandy mudstone, grayish orange 10 YR 7/4 and medium dark gray N4 mudstone with very fine grained sand, granule sized angular gray clasts, some organics grading into medium dark gray sandy mudstone	370
1722.8	1723.0	0.2	lignite and mudstone, black N1 lignite and grayish black N2 interlaminated mudstone	
1723	1723.8	0.8	silty mudstone, medium dark gray N4	
1723.8	1724.0	0.2	sandstone, light olive gray 5Y 5/2, fine grained quartz sand	
1724	1725.7	1.7	silty mudstone, medium dark gray N4, slightly silty, slickensides, grading into more silt and some fine grained sand	
1725.7	1728.9	3.2	sandy mudstone, medium gray N5 and medium light gray N6, silty mudstone interbedded with lighter colored sandy mudstone, laminations disturbed, some organic material observed	371
1728.9	1729.2	0.3	silty mudstone, grayish green 10G 4/2	
1729.2	1729.7	0.5	lignite, black N1	
1729.7	1730.0	0.3	core lost	
1730	1731.5	1.5	silty mudstone, grayish black N2, slightly silty mudstone, poorly	

			consolidated, brittle surface	372
1731.5	1734.5	3.0	sandy mudstone, medium bluish gray 5B 5/1 silty mudstone and medium light gray N6 sandy mudstone laminations, slightly disturbed in the middle, finely laminated at the basal end (1mm)	
1734.5	1737.0	2.5	silty mudstone, medium dark gray N4 silty mudstone and light gray N7 siltstone interlaminated, fine laminations, some disturbed	373
1737	1746.9	9.9	silty mudstone, medium bluish gray 5B 5/1, mottled, clay rip-up clasts, at 1738.2 the color is medium gray N5 mottled with medium light gray N6 bioturbated laminations, one burrow is filled with calcareous matter at 1740.2, core becomes more massive at 1744, organics	374-376
1746.9	1751.6	4.7	sandy mudstone, greenish gray 5G 6/1 silty mudstone mottled with light greenish gray 5G 8/1 sandy mudstone, very fine grained sand, mostly silty with some bioturbation and clay rip-ups, low angle crossbeds observed between 1751.1-1751.2	377
1751.6	1751.7	0.1	silty mudstone , medium dark gray N4	
1751.7	1752.0	0.3	core lost	
1752	1752.7	0.7	silty mudstone, medium gray N5, some disrupted laminations and floating yellow clasts	378
1752.7	1752.8	0.1	silty mudstone, pale yellowish brown 10YR 6/2, very slight amounts of silt (less than 1 mm laminations)	
1752.8	1753.4	0.6	silty mudstone, medium dark gray N4 mudstone, fractured and filled with white N9 calcareous cement, fractured vertically	
1753.4	1757.0	3.6	silty mudstone, pale yellowish brown 10YR 6/2, very slight amounts of silt (less than 1 mm laminations, at 1753.8 the color changes to dark gray N3, slightly silty, brittle core surface, some grayish orange 10 YR 7/4 floating mud clasts	
1757	1761.9	4.9	sandy mudstone, very light gray N8 to light gray N2 sandy mudstone and medium gray N5 silty mudstone, very fine-fine quartz sand, fining upwards, mod. well sorted, thin horizontal laminae, some wavy, from 1757-1758 fine blebs, bioturbated	379
1761.9	1762.0	0.1	core lost	
1762	1769.0	7.0	silty mudstone, medium gray N5, some medium light gray N6 sandy mudstone laminae, very fine grained, moderately well sorted, 45 degree angled crossbeds at 1762-1763.2, indurated. At 1764-1767 massive silty mudstone, fissile, root traces, at 1767.8 clay blebs (<4mm)	380
1769	1774.7	5.7	silty mudstone, dark gray N3 in upper portion, medium gray N5 in lower portion, well sorted, massive, slickensides, dark organic rich upper layers, fissile, some coarser bedding after 1773.6, organics throughout	381-382
1774.7	1775.9	1.2	muddy sandstone, medium gray N5 muddy sandstone to very fine sandstone w/ laminations, very bioturbated, laminations disappear towards the bottom of the unit, scattered organics	383
1775.9	1777.0	1.1	sandy mudstone, light gray N7 muddy sandstone or sandy mudstone with bioturbation and not much bedding, some very fine sand areas throughout	

1777	1777.9	0.9	sandstone, medium gray N5 to medium dark gray N4, very fine grained, intensely laminated and bioturbated, some trough cross-beds, everything is on a slant (angled)	
1777.9	1785.2	7.3	silty mudstone, medium dark gray N4, well sorted, wavy crossbedding, subtly fining upwards	384-385
1785.2	1790.1	4.9	silty mudstone, medium gray N5 and pale yellow orange 10 YR 8/2, massive with tilted lenses of brown silty mudstone	386
1790.1	1794.6	4.5	silty mudstone , light gray N7, massive, root cast at 1790.6-1790.9, thin medium dark gray N4 clay laminations increasing towards base	387
1794.6	1799.4	4.8	silty mudstone , light olive gray 5Y 6/1, massive, some floating small clay clasts, laminations formed by lignitic lenses below 1797.6 oriented horizontally, indurated	388
1799.4	1801.9	2.5	silty mudstone, medium gray N5 to medium dark gray N4, organic clasts from 1800.5-1800.6, bioturbation, soft sediment deformation at 1800.4	389
1801.9	1802.0	0.1	core lost	
1802	1805.8	3.8	silty mudstone, pale yellowish brown 10 YR 6/2 some soft sediment deformation, organics, section with fine laminations after 1804.6	390
1805.8	1806.8	1.0	silty mudstone, grayish black N2 claystone and medium dark gray N4 silty mudstone layered in 0.1' intervals	
1806.8	1809.0	2.2	claystone, grayish black N2, slickensides, poorly consolidated, organic material	
1809	1809.4	0.4	silty mudstone, medium dark gray N4, slightly silty, slickensides, some organic material	
1809.4	1809.6	0.2	core lost	
1809.6	1813.8	4.2	claystone, grayish black N2, slickensides, some organic material, organic bedding, uniform, brittle core surface	391
1813.8	1814.5	0.7	silty mudstone, medium dark gray N4, organic material	
1814.5	1814.6	0.1	core lost	
1814.6	1816.2	1.6	silty mudstone, dark gray N3, uniform, organic bits floating, brittle core surface	392
1816.2	1816.9	0.7	carbonaceous mudstone, brownish black 5YR 2/1, laminated with black organics on bedding planes	
1816.9	1820.7	3.8	lignite, black N1 lignite	393
1820.7	1821.7	1.0	mudstone, brownish black 5YR 2/1 and black N1 carbonaceous mudstone and lignite	
1821.7	1823.1	1.4	claystone, grayish black N2, gradational contact	
1823.1	1824.2	1.1	silty mudstone, medium dark gray N4 to N5, almost a claystone but slightly silty with darker organic layers	394
1824.2	1827.2	3.0	claystone, grayish black N2, gradational contact, at 1825.6 the color changes to a medium light gray N6 to N5 with thick coal at 1826	
1827.2	1828.0	0.8	silty mudstone, grayish black N2 silty mudstone, very organic	
1828	1833.0	5.0	silty mudstone, medium light gray N6 to dark gray N3, massive, well	

			sorted, fissile, indurated, bioturbated from 1824-1830.6 and silty blebs from 1830-1831 (approximately 12mm)	395
1833	1838.4	5.4	silty mudstone , dark greenish gray 5G 4/1 in upper portion of the unit, to medium dark gray N4 at the lower part, massive, fissile, rare clay blebs at1833.9', scattered organic material at the base of the unit, slickensides	396
1838.4	1841.9	3.5	lignite, black N1, tonstein layers at 1841.5-1841.6	397
1841.9	1843.9	2.0	silty mudstone, medium dark gray N4, well sorted, fissile, slickensides, massive	398
1843.9	1844.5	0.6	silty mudstone, medium light gray N6, laminated, silt lenses, possible burrows or root traces	
1844.5	1844.9	0.4	silty mudstone , dark gray N3, massive, well sorted, leaf fossils	
1844.9	1845.0	0.1	core lost	
1845	1847.0	2.0	silty mudstone, medium dark gray N4, well sorted, laminations, organic fragments on bedding planes, indurated	399
1847	1847.5	0.5	lignite, black N1, massive, slickensides, organics	
1847.5	1847.8	0.3	core lost	
1847.8	1851.4	3.6	lignite, black N1 to grayish black N2, small fine grained sand bed observed at 1848.2, mostly coal with very small clay clasts (2-3mm), fissile, well sorted 400	
1851.4	1855.2	3.8	sandstone, grayish black N2 in upper portion grading into a light olive gray 5Y 6/1 at the base, lower medium sized grains, moderately well sorted, quartz with lignite grains and larger organics further down, rounded, massive	401
1855.2	1865.2	10.0	sandstone , light gray N7-N6, well sorted, clean quartz sandstone, subangular to subrounded, possible bedding	402
1865.2	1884.3	19.1	sandstone , light gray N7-N6, same as above, pebble sized dark gray N3 fine grained clast at 1867.0	403

Casing set and redrilling of section necessitated by cave-in. A portion of the section is re-cored

1797	1801.8	4.8	silty mudstone, med. gray N5, highly slickensides, fine blebs at 1797.7, poorly developed laminations and organics on bedding planes, woody material at 1800.8	1A
1801.8	1802.5	0.7	lignite, grayish-black N2 with leaf fragments	2A
1802.5	1804.4	1.9	silty mudstone, med. dark gray N4, massive between 1802.5-1803.1, laminated between 1803.1-1804.4	
1804.4	1805.0	0.6	core lost	
1805	1806.9	1.9	silty mudstone, dark gray N3 to medium dark gray N4 with zones of grayish black N2 claystone	3A
1806.9	1807.1	0.2	lignite	
1807.1	1808.1	1.0	silty mudstone, dark gray N3 to medium dark gray N4 with zones of	

			grayish black N2 claystone	
1808.1	1808.2	0.1	lignite	
1808.2	1813.8	5.6	silty mudstone, dark gray N3 to medium dark gray N4 with zones of grayish black N2 claystone	
1813.8	1816.2	2.4	claystone, med. dark. gray N4 with slickensides	4A
1816.2	1816.8	0.6	silty mudstone, med. gray N4 with lighter blebs of claystone	5A
1816.8	1820.4	3.6	lignite, black N1	
1820.4	1821.0	0.6	lignite, brownish black 5YR 2/1	6A
1821	1824.0	3.0	claystone, dark. gray N3, abundant slicks	
1824	1825.9	1.9	lignite, black N1	7A
1825.9	1826.3	0.4	claystone, grayish black N2	
1826.3	1827.4	1.1	silty mudstone, black to grayish black N1-N2	
1827.4	1827.8	0.4	lignite/claystone, black claystone N1 with lignite interbeds	
1827.8	1829.5	1.7	claystone, dark gray N3 with abundant slickensides	
1829.5	1838.0	8.5	silty mudstone, medium gray N4, fissile with slickensides	8A-9A
1838	1838.8	0.8	claystone, dark clay N3 with slickensides	9A
1838.8	1842.1	3.3	lignite, black N1 with tonstein blebs	10A
1842.1	1842.2	0.1	core lost	11A
1842.2	1844.5	2.3	silty mudstone, medium dark gray N4, fissile	
1844.5	1846.8	2.3	silty mudstone, grayish black N2 with medium dark gray laminations N4	12A
1846.8	1850.5	3.7	lignite, black N1, some amber	
1850.5	1855.3	4.8	sandstone, moderate brown 5YR 4/4 fine-grained quartz, rounded, well-sorted, massively bedded, organics, becoming brown 5YR 2/2 at 1852.5 and pale brown 5YR 5/2 at 1853.8	13A-14A
1855.3	1861.5	6.2	sandstone, medium light gray N7, medium to coarse grained, subrounded to well-rounded, well-sorted, massive, 99% quartz	15A
1861.5	1862.3	0.8	core lost	16A
1862.3	1865.0	2.7	sandstone, medium light gray N7, medium to coarse grained, subrounded to well-rounded, well-sorted, massive, 99% quartz	
1865	1884.0	19.0	sandstone, medium light gray N6, medium fining up to fine grained, well-rounded, well-sorted, massive, quartz, dark gray metallic nodule at 1866.5, 1872.4, thin black lamination of mica at 1875, grayish orange pink 5YR 7/2 lamination at 1879.2	17A-20A
1884	1887.0	3.0	core lost	
1887	1889.1	2.1	sandstone, medium light gray N7, medium to very coarse grained, rounded to sub-rounded, 99% quartz	21A
1889.1	1890.0	0.9	core lost	
1890	1895.0	5.0	sandstone, medium light gray N7, medium to very coarse grained, rounded to sub-rounded, 99% quartz, very coarse between 1891-2	22A
1895	1897.6	2.6	sandstone, med. light gray N7, fine grained, well-rounded, well-sorted, massive	23A
1897.6	1898.0	0.4	sandstone, coarse, poorly sorted, quartz	
1898	1905.2	7.2	sandstone, med. light gray N7, fine grained, well-rounded, well-	

			sorted, massive	24A
1905.2	1915.2	10.0	sandstone, very fine grained, light gray N7 to medium dark gray N4, poorly sorted at top but moderately well-sorted throughout, subrounded, quartz, bioturbated in places	25A-26A
1915.2	1923.0	7.8	sandstone, fine to medium grained, with organics, bioturbation from 1916.5-1919, medium light gray N6 to med. gray N5, subrounded, sometimes silty, fining upwards	27A-28A
1923	1935.2	12.2	sandstone, med. grained, med. gray N5 at top and lt. gray at base, with large horizontal and vertical burrows between 1926-1927	28A-30A
1935.2	1940.2	5.0	sandstone, medium grained, dark. greenish gray 5G4/1, subrounded, bioturbated with large horizontal and vertical burrows, quartz	31A
1940.2	1945.2	5.0	sandstone, medium grained, medium gray N5, rounded to subrounded, bioturbated between 1940-1941, quartz	32A
1945.2	1949.2	4.0	sandstone, medium light gray N7, fine grained, well-sorted, large horizontal burrows at 1948 (15mm), subrounded	33A
1949.2	1949.5	0.3	core lost	
1949.5	1954.5	5.0	sandstone, medium light gray N6-N7, fine-med. grained, well-sorted, some shaley layers	34A
1954.5	1959.5	5.0	sandstone, light gray N7 to medium light gray N6, very fine to fine grained, salt and pepper (20% dark grains), subangular to subrounded, clear smoky quartz	35A
1959.5	1964.3	4.8	sandstone, medium dark gray N4-5, fine grained, well-sorted	36A
1964.3	1964.5	0.2	core lost	
1964.5	1984.5	20.0	muddy sandstone, medium dark gray N4 to medium light, gray N6, fine grained with thin mudstone and siltstone laminations, shell fragments with mother of pearl, pyrite crystals, carbonate cemented layers	37A-40A
1984.5	1988.3	3.8	silty mudstone, medium dark gray N4 , bioturbated, shell fragments	
1988.3	1989.0	0.7	sandstone, medium gray N5, fine-med. grained, well-sorted, quartz	
1989	1989.6	0.6	silty mudstone, medium dark gray N4,bioturbated, shell fragments	41A
1989.6	1993.9	4.3	muddy sandstone, medium gray N5, interbedded, bioturbated from 1991-1993.9	42A
1993.9	1994.0	0.1	core lost	
1994	1998.2	4.2	silty mudstone medium dark gray N5, interbedded fine sands, shell fragments, burrows	43A
1998.2	1999.0	0.8	sandstone, medium light gray, very fine grained	
1999	2003.8	4.8	sandy mudstone, medium light gray N6 to medium dark gray N4 burrows	44A
2003.8	2009.1	5.3	siltstone, medium gray N5, bioturbated, shell fragments	45A
2009.1	2015.2	6.1	muddy sandstone, medium gray N5, very fine grained, scattered shell fragments, bioturbated at base	46A
2015.2	2016.4	1.2	sandstone, light gray N7, very fine grained, carbonate cemented	47A

2016.4	2018.1	1.7	muddy sandstone, medium dark gray, bioturbated	
2018.1	2033.9	15.8	muddy sandstone, olive gray 5Y 4/1 to light gray N7 and N5, interbedded sandstone and siltstone, severely bioturbated, shell fragments	48A
2033.9	2034.9	1.0	sandstone, fine grained	51A
2034.9	2040.5	5.6	sandy mudstone, medium gray N5, interbedded sandstone and siltstone, severely bioturbated	52A
2040.5	2044.5	4.0	muddy sandstone, dark greenish gray 5GY 4/1, highly bioturbated	53A
2044.5	2051.2	6.7	sandy mudstone, medium gray N5 to medium dark gray N4, highly bioturbated, sand-filled burrows, some shell fragments	54A-56A
2051.2	2072.0	20.8	silty mudstone, medium gray N5, highly bioturbated, sand-filled burrows, some shell fragments, vertical pipe burrow at 2054.2-2054.6	56A-60A
2072	2072.2	0.2	sandstone, light gray N7, very fine grained, horizontal laminae	60A
2072.2	2072.3	0.1	claystone	
2072.3	2072.8	0.5	sandstone, light gray N7, very fine grained, with shell hash, shale rip-ups, hackly appearance	
2072.8	2117.4	44.6	sandstone, light gray N7 to medium dark gray N4, very fine grained, indurated with CaCO3 cement above 2075.4, massive, quartz well sorted, low angle cross beds enhanced by dark minerals between 2102-2105, shell fragments at 2013.9	60A-69A
2117.4	2118.9	1.5	mudstone, dark gray N3 - N4, calcareous	
2118.9	2120.1	1.2	sandstone	
2120.1	2120.3	0.2	mudstone, dark gray N3, calcareous	70A
2120.3	2124.3	4.0	sandstone, medium light gray N6 sandstone and medium dark gray silty mudstone interbeds, bioturbated, calcareous cement, some minor cross beds, some shells including gastropods	
2124.3	2127.5	3.2	silty mudstone, medium gray N5 and light brownish gray 5YR 6/1, heavily bioturbated but also some zones of fine laminations	71A
2127.5	2129.5	2.0	sandstone, medium light gray N6 sandstone and medium dark gray N4 silty mudstone interbeds, bioturbated, calcareous cement in mud but not sands, soft sediment deformation at 2128.6-2128.7	
2129.5	2130.3	0.8	muddy sandstone, grayish black N2 laminations and medium light gray N6 fine sand, subrounded, poorly sorted, quartz	72A
2130.3	2130.6	0.3	silty mudstone, dark gray N3, horizontally bedded	
2130.6	2134.0	3.4	sandstone, medium light gray N6, fine sandstone, subrounded, mod. well to well sorted, quartz, very thin laminations of darker grains	
2134	2134.3	0.3	core lost	
2134.3	2134.6	0.3	sandstone, medium gray N5, fine sand, subrounded, poorly sorted , quartz	73A
2134.6	2134.9	0.3	sandstone, medium light gray N6 sandstone and dark gray N3 silty mudstone interbeds, bioturbated, soft sediment deformation	

2134.9	2136.4	1.5	sandstone, medium gray N5, fine sand, subrounded, mod well sorted, quartz, fine laminations	
2136.4	2138.9	2.5	sandstone, medium light gray N6 sandstone and dark gray N3 silty mudstone interbeds, bioturbated, soft sediment deformation	
2138.9	2139.5	0.6	sandstone, medium gray N5, fine sand, subrounded, mod well sorted, quartz, fine laminations	
2139.5	2140.9	1.4	muddy sandstone, medium light gray N6, poorly sorted, subangular, fine horizontal laminations, quartz	74A
2140.9	2144.0	3.1	sandstone, medium light gray N6 sandstone and dark gray N3 to medium gray N5 silty mudstone interbeds, bioturbated, some fine laminae, calcareous cement	
2144	2144.4	0.4	core lost	
2144.4	2154.3	9.9	silty mudstone, grayish black N2 to medium light gray N6, bioturbated in broad zones, cross-beds, horizontal laminae, calcareous cement, gastropod at 2150.7	75A-76A
2154.3	2159.3	5.0	silty mudstone, medium dark gray N4, quartz and silt component, well sorted, bioturbated throughout, few fine sand laminations, 2157.4-2157.5 bivalve assemblage	77A
2159.3	2164.3	5.0	sandy mudstone, medium dark gray N4 to dark gray N3, sandy component is fine to v. fine, moderately well sorted, indurated, some laminations but mostly bioturbated, 2161.0-2164.3 bivalve fragments	78A
2164.3	2169.3	5.0	muddy sandstone, medium dark gray N4 to dark gray N3, fining upwards, sand size varies from med./fine sand to fine/v. fine sand, bioturbation, terebellina trace fossils, scattered bivalve fragments between. 2167.0-2169.0, moderately well sorted	79A
2169.3	2176.1	6.8	muddy sandstone, medium dark gray N4 dark gray N3, medium to fine grained, laminar structure disrupted by bioturbation, scattered fossil mollusk fragments (predominantly bivalves w/ rare gastropods), rare organic material, mod. well sorted, scattered calcareous nodules.	80A-81A
2176.1	2179.5	3.4	sandstone, medium dark gray N4 to medium gray N5, fine grained, basal portion has greater proportion of mud than upper portion, 2176.05-2177.1' massive sandstone, bivalve fragments, highly bioturbated, terebellina trace fossil, calcareous nodules, mod. well sorted	81A-82A
2179.5	2181.8	2.3	sandstone, medium gray N5 to med. dark gray N4, fine-grained, bioturbation, scattered mollusk fragments, calcareous nodule, moderate well sorted, indurated 82A	
2181.8	2185.9	4.1	limey sandstone, light gray N7, fine to very fine sand, moderately well sorted to well sorted, rare laminations, mostly bioturbated, some yellowish calcareous concretions,	82A -83A
2185.9	2189.9	4.0	silty mudstone medium dark gray N4, some darker silty areas, sharp	

			contact, some calcareous concretions, slightly black organic flecks, bioturbated, dark gray N3 shale clast at 2189.5, heavily churned sand	83A
2189.9	2195.0	5.1	muddy sandstone, dark gray N3 and medium gray N5, very fine grained, extremely bioturbated, occasional black organic flecks, weekly laminar at base	84A
2195	2196.8	1.8	muddy sandstone, medium light gray N6, bioturbated, interbedded and finely laminated at base	85A
2196.8	2196.9	0.1	silty mudstone, dark gray N4	85A
2196.9	2200.0	3.1	sandy mudstone, medium light gray N6 and medium gray N5, bioturbated, large yellowish-gray (5Y 7/2) clast at 2198.9 and some smaller clasts at basal end of core are calcareous nodules	85A
2200	2204.3	4.3	muddy sandstone, medium dark gray N4, very fine grained, fining upward, bioturbated, contains occasional shell fragments, calcareous concretions and black organic stringers (2203-2203.5), angular grains, quartz with mica and a few feldspar grains	86A
2204.3	2208.9	4.6	muddy sandstone, medium dark gray N4 to medium light gray N5 interbedded and bioturbated, some slightly calcareous areas, very fine-grained, angular grains, some shell fragments, organic fragments	87A
2208.9	2213.8	4.9	muddy sandstone, very light gray N2 and medium dark gray N3, very fine sand, angular, poorly sorted, heavily bioturbated, burrows, bivalve fossil, mottled appearance	88A
2213.8	2218.6	4.8	muddy sandstone, medium gray N5, very fine-grained, angular, quartz and mica composition, some black organic stringers, well sorted, bioturbated giving core mottled appearance, indurated, some shell fragments.	89A
2218.6	2223.4	4.8	muddy sandstone, medium dark gray N4 and dark gray N5, very fine grained, angular grains, well sorted, crushed shell material, calcareous nodule, bioturbated, organics	90A
2223.4	2228.3	4.9	muddy sandstone, medium gray N5, carbonate concretions at 2224.5, severely bioturbated, shell fragments and organics throughout, fine-grained, at 2227.4 grayish-orange 10YR 7/4 layer containing silt, organics, calcareous	91A
2228.3	2230.9	2.6	muddy sandstone, medium gray N5 and dark gray N3 interbedded and bioturbated, some terebellina traces, organics, sandy at base	92A
2230.9	2235.9	5.0	sandy mudstone, medium gray N5, fine grained sand and silt, bioturbated, terebellina traces, calcareous orange-gray layers observed at 2231.2, 2234.6, and 2235.4, organics	93A
2235.9	2240.9	5.0	muddy sandstone, dark gray N3 and light gray N7, very fine grained, heavily bioturbated, burrows, calcareous concretion 2236.2	94A
2240.9	2256.0	15.1	silty mudstone, dark gray N3 and lt. gray N7, bioturbated w/ rip-ups of laminated silty shale and some preserved fine laminations,	

burrows, soft sediment deformation terebellina traces, calcareous
concretions, shell material 95A 96A 97A

Table 3. Hydraulic Conductivity Data - Kiowa Core Samples 1999

				Permeability Measurements in cm/s			
Sample #	Depth	Lithology	Aquifer	Run 1	Run 2	Run 3	AVERAGE
1A	91.5-92.5	MSS	Dawson	7.59E-05	7.53E-05	7.45E-05	7.52E-05
2A	100-100.75	SMS	Dawson	1.35E-04	1.35E-04	1.35E-04	1.35E-04
3A	122.3-123.1	SS	Dawson	4.31E-05	3.90E-05	3.58E-05	3.93E-05
4A	134.2-134.9	MSS	Dawson	4.40E-04	4.47E-04	4.39E-04	4.42E-04
5A	150.9-152	MSS	Dawson	4.16E-04	4.36E-04	4.18E-04	4.23E-04
6A	175.5-176.5	SS	Dawson	5.03E-05	4.88E-05	5.41E-05	5.10E-05
7A	180.5-181.3	ZMS	Dawson	2.71E-04	no data	no data	2.71E-04
8A	200.3-201.1	MSS	Dawson	1.44E-05	1.54E-05	1.42E-05	1.46E-05
9A	243.3-244.1	GSS	Dawson	2.27E-04	2.20E-04	2.27E-04	2.24E-04
10A	286.1-286.8	MSS	Dawson	5.46E-07	6.23E-07	5.64E-07	5.78E-07
11A	339.1-340.0	SMS	Dawson	7.71E-08	9.44E-08	8.45E-08	8.53E-08
12A	367.8-368.6	MSS	Denver	1.98E-05	1.96E-05	no data	1.97E-05
13A	428.5-429.4	ZMS	Denver	3.97E-07	3.83E-07	3.75E-07	3.90E-07
14A	387.2-388.2	SMS	Denver	1.01E-04	9.78E-05	9.53E-05	9.80E-05
15A	524-524.7	MSS	Denver	5.74E-04	5.74E-04	5.74E-04	5.74E-04
16A	565.1-565.9	SS	Denver	1.09E-04	1.09E-04	1.09E-04	1.09E-04
17A	600-600.7	CbMS	Denver	1.73E-06	1.63E-06	1.78E-06	1.71E-06
18A	619-620	MSS	Denver	1.19E-05	1.07E-05	1.10E-05	1.12E-05
19A	697.7-698.5	SS	Denver	3.95E-05	3.87E-05	3.87E-05	3.90E-05
20A	772.8-773.8	CS	Denver	no data	no data	no data	no data
21A	851.7-852.7	SS	Denver	5.39E-06	3.24E-06	2.56E-06	3.73E-06
22A	911.3-912.1	ZS	Denver	no data	no data	no data	no data
23A	942.4-943.4	MSS	Denver	2.18E-04	2.20E-04	2.17E-04	2.18E-04
24A	976.3-977.5	SS	Denver	1.27E-04	1.28E-04	1.32E-04	1.29E-04
25A	1061-1062	SS	Denver	3.19E-03	3.17E-03	3.21E-03	3.19E-03
26A	1122.5-1123.5	CS	Arapahoe	no data	no data	no data	no data
27A	1177-1178.2	SS	Arapahoe	3.52E-05	3.38E-05	3.12E-05	3.34E-05
28A	1245.6-1246.5	MSS	Arapahoe	1.94E-06	1.66E-06	1.22E-06	1.61E-06
29A	1285.5-1287.2	SS	Arapahoe	1.51E-05	no data	no data	1.51E-05
30A	1349.5-1350.5	ZS	Arapahoe	1.25E-05	1.30E-05	1.19E-05	1.25E-05
31A	1297.7-1298.2	SMS	Arapahoe	1.49E-05	1.45E-05	1.43E-05	1.46E-05
32A	no data	SS	Arapahoe	4.36E-04	4.39E-04	4.36E-04	4.37E-04
33A	1458-1459	SS	Arapahoe	1.78E-06	1.56E-06	1.15E-06	1.50E-06
34A	1492.5-1493.7	SS	Arapahoe	2.43E-04	no data	no data	2.43E-04
35A	1528-1529.2	SS	Arapahoe	1.00E-06	9.37E-07	7.28E-07	8.88E-07
36A	1562.1-1563	GMS	Arapahoe	3.19E-06	2.27E-06	2.04E-06	2.50E-06
37A	1623.6-1624.6	SS	Arapahoe	1.35E-07	1.68E-07	1.45E-07	1.49E-07
38A	1634.9-1635.8	MCg	Arapahoe	3.24E-07	3.22E-07	2.87E-07	3.11E-07
39A	1680.3-1681	ZMS	Arapahoe	no data	no data	no data	no data
40A	1749-1750	SMS	Arapahoe	3.46E-05	3.28E-05	3.53E-05	3.42E-05
41A	1846.3-1846.6	ZMS	L-Fox Hills	1.67E-05	1.62E-05	1.66E-05	1.65E-05
42A	1883-1883.8	SS	L-Fox Hills	8.48E-04	8.44E-04	8.48E-04	8.47E-04
43A	1926.8-1928	SS	L-Fox Hills	2.74E-05	2.65E-05	2.56E-05	2.65E-05
44A	1962.8-1963.6	SS	L-Fox Hills	9.99E-05	9.95E-05	9.95E-05	9.96E-05
45A	2012-2013.2	MSS	L-Fox Hills	1.70E-05	1.78E-05	1.76E-05	1.75E-05
46A	2046.4-2047.3	SMS	L-Fox Hills	7.35E-06	6.49E-06	6.19E-06	6.68E-06
47A	2080.1-2080.9	SS	L-Fox Hills	2.18E-04	2.21E-04	2.19E-04	2.19E-04
48A	2131.1-2132	SS	L-Fox Hills	6.34E-04	6.31E-04	6.44E-04	6.36E-04
49A	2183.9-2184.7	no data	L-Fox Hills	4.23E-07	2.80E-07	3.26E-07	3.43E-07
50A	2193.7-2194.7	no data	L-Fox Hills	2.08E-06	2.80E-06	2.66E-06	2.51E-06
51A	2220-2220.9	no data	L-Fox Hills	4.86E-05	4.75E-05	4.91E-05	4.84E-05
52A	2242-2242.8	MSS	L-Fox Hills	2.69E-07	1.54E-07	1.71E-07	1.98E-07
53A	1090	fine	Denver	no data	no data	no data	no data
54A	1590	fine	Arapahoe	4.14E-06	4.26E-06	3.20E-06	3.87E-06
55A	480	fine	Denver	4.11E-05	4.14E-05	3.18E-05	0.00E+00

Table 4. Porosity and Specific Yield Data from the Kiowa #1 core

Sample #	Depth	Lithology	Final Porosity	Final Specific Yield
1A	91.5-92.5	MSS	0.27	0.12
2A	100-100.75	SMS	0.36	0.10
3A	122.3-123.1	SS	0.25	0.07
4A	134.2-134.9	MSS	0.29	0.20
5A	150.9-152	MSS	0.42	0.29
6A	175.5-176.5	SS	0.31	0.18
7A	180.5-181.3	ZMS	0.57	0.29
8A	200.3-201.1	MSS	0.49	0.30
9A	243.3-244.1	GSS	0.33	0.15
10A	286.1-286.8	MSS	0.37	0.13
11A	339.1-340.0	SMS	0.38	0.08
12A	367.8-368.6	MSS	0.29	0.04
13A	428.5-429.4	ZMS	0.41	0.13
14A	387.2-388.2	SMS	0.64	0.28
15A	524-524.7	MSS	0.45	0.20
16A	565.1-565.9	SS	0.26	0.10
17A	600-600.7	Lig	0.30	0.02
18A	619-620	MSS	0.33	0.09
19A	697.7-698.5	SS	0.37	0.12
20A	772.8-773.8	CS	0.36	0.07
21A	851.7-852.7	SS	0.35	0.11
22A	911.3-912.1	ZS	0.31	0.06
23A	942.4-943.4	MSS	0.33	0.10
24A	976.3-977.5	SS	0.40	0.26
25A	1061-1062	SS	0.39	0.29
26A	1122.5-1123.5	CS	0.57	0.26
27A	1177-1178.2	SS	0.34	0.12
28A	1245.6-1246.5	MSS	0.34	0.10
29A	1285.5-1287.2	SS	0.23	0.09
30A	1349.5-1350.5	ZS	0.32	0.14
31A	1297.7-1298.2	MSS	0.32	0.09
32A	1386-1387	SS	0.42	0.25
33A	1458-1459	SS	0.34	0.08
34A	1492.5-1493.7	SS	0.30	0.02
35A	1528-1529.2	SS	0.35	0.05
36A	1562.1-1563	GMS	0.32	0.18
37A	1623.6-1624.6	SS	0.20	0.01
38A	1634.9-1635.8	MCg	0.28	0.08
39A	1678.9-1679.7	SMS	0.42	0.05
40A	1749-1750	SMS	0.34	0.12
41A	1846.3-1846.6	ZMS	0.35	0.13
42A	1883-1883.8	SS	0.43	0.27
43A	1926.8-1928	SS	0.35	0.23
44A	1962.8-1963.6	SS	0.41	0.10
45A	2012-2013.2	MSS	0.23	0.02
46A	2046.4-2047.3	SMS	0.28	0.06
47A	2080.1-2080.9	SS	0.39	0.10
48A	2131.1-2132	SS	0.36	0.20

Table 5. Grain size analysis of samples from the Kiowa #1 core

Percent finer than the following sieve sizes in millimeters

Sample #	0.062	0.088 0.1	25 0.177	0.25	0.354	0.5	0.707	1	1.414	2	2.8	4 5	6 8	11.31		4	16
1A	6.3	8.1	11.9	18.8	36.0	70.3	81.6	95.5	99.2	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2A	33.6	39.3	47.4	56.7	69.0	78.6	92.3	99.3	99.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3A	11.1	14.4	19.6	26.9	43.9	65.7	85.3	95.5	98.5	99.4	99.8	99.9	100.0	100.0	100.0	100.0	100.0
4A	2.9	4.0	6.6	10.0	16.8	25.9	43.4	67.2	88.7	98.0	99.7	100.0	100.0	100.0	100.0	100.0	100.0
5A	3.4	4.7	7.1	10.7	18.2	33.0	56.3	79.7	92.6	97.6	99.2	99.6	99.8	100.0	100.0	100.0	100.0
6A	5.1	6.7	9.7	13.9	20.6	31.3	48.4	73.1	89.3	95.9	98.3	99.3	99.8	99.9	100.0	100.0	100.0
7A	24.9	39.8	45.4	56.2	67.7	81.5	97.0	99.3	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
8A	3.8	5.8	10.5	18.6	37.5	64.6	87.6	96.9	99.0	99.5	99.7	99.8	100.0	100.0	100.0	100.0	100.0
9A	6.3	8.4	12.4	17.2	23.4	29.4	36.7	46.3	57.1	69.0	81.5	91.1	98.0	99.7	100.0	100.0	100.0
10A	27.0	41.6	49.5	61.8	73.1	84.2	97.2	99.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
11A	24.5	37.2	50.0	65.4	82.6	96.4	98.4	99.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12A	6.8	8.9	14.0	21.3	34.6	53.4	72.0	85.1	92.3	96.0	98.0	99.0	99.7	100.0	100.0	100.0	100.0
13A	14.5	21.9	37.1	57.1	76.9	88.4	97.0	99.3	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
14A	26.0	37.1	49.8	63.8	81.1	98.4	99.7	99.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
18A	18.2	29.9	56.1	81.4	95.9	99.2	99.5	99.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19A	15.9	26.6	49.0	75.6	92.2	95.9	98.3	99.6	99.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
20A	36.8	47.7	58.4	70.5	86.0	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
21A	45.3	59.5	69.3	75.3	83.7	95.2	99.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
22A	38.4	65.4	95.4	99.3	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
23A	52.4	66.2	73.9	81.4	91.3	99.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
24A	7.2	9.9	15.7	21.2	39.0	75.7	94.0	98.8	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
25A	4.8	6.5	10.6	15.5	32.9	74.3	91.8	97.7	99.3	99.6	99.7	99.9	100.0	100.0	100.0	100.0	100.0
26A	31.6	40.6	48.1	58.4	71.5	91.9	96.1	98.7	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
27A	1.3	4.8	11.3	26.7	55.6	96.1	99.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
28A	43.5	58.3	70.5	78.5	83.4	86.8	91.9	95.6	98.5	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0
29A	4.4	6.3	10.0	16.9	52.2	92.4	98.6	99.2	99.4	99.5	99.5	99.6	99.6	99.6	99.6	100.0	100.0
30A	21.9	52.4	80.3	89.9	95.2	98.1	99.5	99.8	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
31A	32.8	38.2	44.4	49.7	57.9	66.7	80.5	91.8	96.1	99.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
32A	2.8	5.7	16.1	45.0	82.7	98.6	99.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
33A	4.3	6.4	10.5	16.0	30.9	70.2	93.6	99.4	99.8	99.9	99.9	99.9	100.0	100.0	100.0	100.0	100.0
34A	2.5	4.6	9.5	20.7	64.7	87.3	96.4	99.0	99.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
35A	17.3	32.5	51.2	69.7	81.0	89.7	97.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
36A	6.2	8.3	12.9	19.9	29.5	37.6	53.1	75.8	89.5	96.4	99.2	99.9	100.0	100.0	100.0	100.0	100.0
37A	1.1	1.7	3.3	5.5	9.1	14.9	26.1	44.8	66.7	84.8	95.8	99.1	99.9	100.0	100.0	100.0	100.0
38A	0.2	0.4	1.0	1.7	2.8	4.0	6.1	9.4	15.2	25.3	41.4	61.4	84.4	96.2	97.7	99.0	100.0
39A	20.2	30.9	39.5	51.9	65.3	84.1	98.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
40A	37.6	54.6	73.3	83.4	91.2	95.2	96.7	98.3	99.4	99.8	99.9	100.0	100.0	100.0	100.0	100.0	100.0
41A	27.6	34.7	43.8	52.9	61.0	70.4	82.1	93.1	97.5	99.4	99.9	100.0	100.0	100.0	100.0	100.0	100.0
42A	0.7	1.0	2.2	10.1	39.4	56.7	70.2	94.9	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
43A	4.5	12.5	32.7	67.8	85.6	94.8	99.6	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
44A	7.6	37.6	76.8	88.7	93.2	97.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
45A	53.0	68.2	75.7	81.2	88.1	94.6	99.1	99.8	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
46A	46.1	52.7	57.3	61.3	66.6	74.3	85.2	94.9	98.1	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0
47A	5.4	32.6	79.7	91.2	96.9	99.3	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
48A	22.1	54.2	87.6	93.8	97.9	99.2	99.5	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
50A	47.0	56.1	61.3	65.6	71.0	77.9	84.3	91.0	95.3	98.4	99.7	100.0	100.0	100.0	100.0	100.0	100.0
51A	16.3	31.4	71.3	86.1	92.0	97.3	98.2	99.0	99.6	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
52A	47.2	59.0	67.8	75.2	80.5	85.8	93.4	98.3	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
53A	34.2	43.1	49.0	55.8	64.9	78.9	98.4	99.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
54A	22.1	33.8	56.9	76.5	85.9	93.2	95.9	98.5	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
55A	7.5	10.5	16.8	24.5	33.1	47.9	71.2	90.4	98.2	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Data from Core Analyses, Aquifer Testing and Geophysical Logging of Denver Basin Bedrock Aquifers at Kiowa, Elbert County, Colorado

Table 6. Palynology samples from the Kiowa #1 core and corresponding age interpretations

Field Number	Core Depth (top)	Core Depth (bottom)	Core Tube	Palynololgy Slides (number of slides - not processed if blank)	Pollen Zone*	Age Interpretation**
FF9901-A	78.10	78.20	2	2		(latest Paleocene or younger)
FF9901-B	95.30	95.40	6	2		(latest Paleocene or younger)
FF9901-C	142.80	142.90	15	2		(latest Paleocene or younger)
FF9901-D	169.90	170.00	20	2		(latest Paleocene or younger)
FF9901-E	219.10	219.20	31	2		(latest Paleocene or younger)
FF9901-F	249.20	249.30	37	3		(latest Paleocene or younger)
FF9901-G	269.80	269.90	41	3		(latest Paleocene or younger)
FF9901-H	307.30	307.40	49	1		(latest Paleocene or younger)
(No field number)	327.20	327.30	53	2	P6/E	latest Paleocene/earliest Eocene
FF9901-I	329.50	329.60	53	4		(latest Paleocene/earliest Eocene)
(No field number)	330.50	330.60	54	2		(latest Paleocene/earliest Eocene)
FF9901-J	332.40	332.50	54	4	P6/E	latest Paleocene/earliest Eocene
(No field number)	335.60	335.70	55	1		(barren - Paleocene)
FF9901-K	336.50	336.60	55	1		(barren - Paleocene)
(No field number)	340.40	340.50	56			(barren - Paleocene)
FF9901-L	352.70	352.80	58	3		(barren - Paleocene)
(No field number)	373.40	373.50	61	2		(barren - Paleocene)
FF9901-M	375.60	375.70	62	2		(barren - Paleocene)
(No field number)	384.70	384.80	64	1		(barren - Paleocene)
FF9901-N	406.80	406.90	69	2		(barren - Paleocene)
(No field number)	411.30	411.50	70	2	P2(P3?)	Paleocene
(No field number)	420.80	420.90	72	2		(Paleocene)
FF9901-O	426.50	426.60	74	2		(Paleocene)
FF9901-P	447.90	no data	79	1		(Paleocene)
FF9901-Q	482.90	483.00	86	2		(Paleocene)
FF9901-R	491.90	492.00	88	2		(Paleocene)
FF9901-S	507.00	507.10	92	2		(Paleocene)
FF9901-T	538.00	538.10	98	2		(Paleocene)
FF9901-U	569.70	no data	unknown	2	P1	Paleocene
FF9901-V	577.10	577.20	106	4		(Paleocene)
FF9901-W	590.60	590.80	109	2	P1	Paleocene
FF9901-X	635.90	636.00	120	2		(Paleocene)
FF9901-Y	656.00	no data	126	2		(Paleocene)
FF9901-Z	679.60	679.60	131			(Paleocene)
FF9901-A2	701.50	701.25	137			(Paleocene)
FF9901-B2	706.40	706.45	138			(Paleocene)
FF9901-C2	716.00	716.10	140			(Paleocene)
FF9901-D2	727.35	727.45	142	4		(Paleocene)
FF9901-E2	742.60	742.70	145			(Paleocene)
FF9901-F2	754.80	754.90	148			(Paleocene)
FF9901-G2	770.30	770.40	152			(Paleocene)
FF9901-H2	783.90	784.00	154			(Paleocene)
FF9901-I2	786.80	786.90	155			(Paleocene)
FF9901-J2	797.00	797.10	158			(Paleocene)
FF9901-K2	810.70	no data	160	2		(Paleocene)
FF9901-L2	817.80	no data	162			(Paleocene)
FF9901-M2	824.90	825.10	164			(Paleocene)
FF9901-N2	835.40	835.50	166			(Paleocene)
FF9901-O2	841.10	641.20	168	2		(Paleocene)
FF9901-P2	647.70	647.80	169			(Paleocene)
FF9901-Q2	857.00	857.10	171			(Paleocene)
FF9901-R2	861.00	861.10	172			(Paleocene)
FF9901-S2	872.00	872.10	175	2		(Paleocene)
FF9901-T2	874.80	874.90	176	2	P1	Paleocene
(No field number)	876.80	876.90	unknown	2	P1	Paleocene
(No field number)	878.30	no data	unknown	2	P1	Paleocene
(No field number)	880.20	880.30	unknown	2	W.s. AZ	Late Creteceous - Maastrichtian
(No field number)	880.50	880.60	unknown	2	W.s. AZ	Late Cretaceous - Maastrichtian
FF9901-U2	881.40	881.45	177	2	W.s. AZ	Late Cretaceous - Maastrichtian
FF9901-V2	890.30	890.40	179	2	W.s. AZ	Late Cretaceous - Maastrichtian
FF9901-W2	899.35	899.40	181	2	W.s. AZ	Late Cretaceous - Maastrichtian
FF9901-X2	910.50	no data	164	2		(Late Cretaceous - Maastrichtian)
FF9901-Y2	922.40	922.50	186	2		(Late Cretaceous - Maastrichtian)
FF9901-Z2	931.50	931.60	189			(Late Cretaceous - Maastrichtian)
FF9901-A3	941.30	941.40	191			(Late Cretaceous - Maastrichtian)
FF9901-B3	953.45	953.50	194	2		(Late Cretaceous - Maastrichtian)
FF9901-C3	962.80	961.85	197			(Late Cretaceous - Maastrichtian)
FF9901-D3	974.80	974.85	199			(Late Cretaceous - Maastrichtian)
FF9901-E3	964.70	984.75	201			(Late Cretaceous - Maastrichtian)
FF9901-F3	994.50	994.55	203	2	W.s. AZ	Late Cretaceous - Maastrichtian

Field Number	*Platycarya platycaryoides*	*Caryapollenites veripites*	*Caryapollenites inelegans*	*Caryapollenites imparalis*	Momipites ventifluminis	*Momipites dilatus*	*Momipites wyomingensis*	*Momipites leffinwellii*	Momipites tenuipolus	Momipites inaequalis	*Momipites sp.*	*Proteacidites thalmanni*	*Proteacidites retusus*	*Proteacidites* spp.	*Aquilapollenites reticulatus*	*Aquilapollenites attenuatus*	*Aquilapollenites quadrilobus*	*Aquilapollenites* spp.
No field number	X	X	X		X						X							
FF9901-J	X	X		X	X													
No field number						X	X	X		X								
FF9901-U								X										
FF9901-W								X										
FF9901-T2								X		X								
No field number									X									
No field number										X								
FF9901-U2											X			X				
FF9901-V2													X			X		
FF9901-W2														X			X	
FF9901-F3													X	X				
FF9901-J3													X	X		X	X	

Table 7. Palynology samples containing age-diagnostic fossils from the Kiowa #1 core

Table 8. Paleomagnetic data from the Kiowa #1 core

Sample	Depth (ft)	a	b	c	d	Mean	Polarity
dba03	83.4	-18.1	-20.1	31.2	6.9		
dba07	101.7	-22.9	-15.6	-38.3	-67.9	-36.2	R
dba18	157.5	9.7	-18.7	-47.4			
dba24	185.6	-44.7	-48.4	-55.4	-23.7	-43.0	R
dba28a	209.6	-33.4	-74.4	-70.3		-59.3	R
dba31a	221.0	-76.4	-75.9	-26.4		-59.6	R
dba32	250.3	-22.3	4.2	-19.1	43.7		
dba38a	287.8	-21.2	-40.2	-39.2		-33.5	R
dba42	317.8	-41.2	-17.2	-38.7		-32.3	R
dba51	384.3	49.2	56.4	53.8	49.4	52.2	N
dba56	407.8	18.7	-13.2	38.6			
dba57	412.2	-69.8	-53.6	-71.5	-69.9	-66.2	REMOVED
dba58	418.3	45.3	57.9	44.3		49.2	N
dba62	432.2	79.8	73.5	68.4	75.6	74.3	N
dba67	453.8	61.2	68.5	72.1	57.9	64.9	N
dba71	472.4	33.8	29.4	6.8	18.3	22.1	N
dba76	498.5	32.8	42.3	43.5	55.4	43.5	N
dba86	546.2	79.0	45.3	51.9	34.6	52.7	N
dba89a	575.8	-48.2	-40.2	-47.0		-45.1	R
dba91	588.0	-67.0	-54.5	-68.8	-50.8	-60.3	R
dba92a	588.5	-71.8	-78.4	-69.5		-73.2	R
dba108	667.3	63.2	64.3	61.2	52.1	60.2	N
dba116	719.5	59.7	31.4	42.0	40.7	43.4	N
dba121	761.7	40.7	48.6	54.0	49.4	48.1	N
dba131	820.7	71.7	44.4	67.3		61.1	N
dba138	851.6	68.1	55.9	55.2	64.9	61.0	N
dba139a	857.9	65.3	65.9	66.5		65.9	N
dba141a	871.4	63.6	60.4	60.8		61.6	N
dba142a	886.0	-49.1	-17.7	-8.6		-25.1	R
dba144a	893.2	0.4	19.2	-8.6			
dba146	902.0	-32.5	-51.6	-28.1	-39.1	-37.8	R
dba149	917.5	-12.0	-20.1	41.0	-14.4		
dba153	934.3	-41.7	-40.2	-44.9	-36.7	-40.9	R
dba157	952.1	-72.6	-79.3	-46.6	-85.0	-70.9	R
dba168	1007.2	-31.5	-30.3	-27.7		-29.8	R
dba176	1041.3	-13.9	-35.4	-14.9	-22.9	-21.8	R
dba179	1054.8	-13.5	-66.7	-23.3		-34.5	R
dba182	1075.7	-30.6	-33.8	-41.5	-38.5	-36.1	R
dba187	1095.7	-42.9	-47.7	-68.1	-46.6	-51.3	R
dba193	1117.0	-46.4	-36.3	-42.2		-41.6	R
dba202	1156.8	-10.7	-39.0	-46.1	-29.8	-31.4	R
dba203a	1160.9	-13.9	-21.2	-25.3		-20.1	R
dba206a	1173.8	-36.5	16.8	-40.8			
dba209a	1203.3	71.1	69.0	42.7		60.9	N
dba214a	1226.0	78.4	60.8	-3.5			
dba218a	1248.5	68.7	67.0	70.8		68.8	N
dba222	1266.8	51.5	53.6	31.3	56.7	48.3	N

Table 9. Petrographic Analysis of Sandstone Samples from the Kiowa Core

	Depth	Grain Size	Sorting	Quartzose	Feldspathic	Lithic	Chert	Ductiles	Carbonate	Volcanic	MonoQuartz	PolyQuartz	Plag	K-Spar	Granitic
D2	92	0.35	0.75	57.1	29.8	13.2	0.5	12.1	0	1	40.3	11.7	11.2	12.6	5.3
	151	0.5	0.5	58	31.7	10.3	0	8.2	0	1.5	38	12.8	10.3	10.3	10.3
	156	0.5	0.45	61.4	31.3	7.3	0	6	0	0.3	39	11	6	13.3	10.7
	200	0.35	0.75	50.8	42.2	7	0	6.4	0	0.6	33.7	14	12.8	15.7	13.4
	243	1.5	1.2	58.4	39.3	2.3	0	1.7	0	0.6	18.1	8.5	4.5	4.5	26
	286	0.15	1.1	45.5	22.6	31.9	0	31.3	0	0	40.5	2.5	3.7	17.8	0.6
Mean D2		0.56	0.79	55.20	32.82	12.00	0.08	10.95	0.00	0.67	34.93	10.08	8.08	12.37	11.05
D1	368	0.75	0.85	29.6	21.4	49	0	5.5	0	40.1	16.3	7.9	4.5	5.5	10.4
	429	0.15	1.1	48.1	11	40.9	1.4	36.9	0	3.6	42.5	2.1	0	10.6	0
	524	0.23	0.65	29.5	19.3	51.1	2.1	31.6	0.5	16.6	20.7	4.1	2.1	15.5	0.5
	565	0.55	1	58.6	21.9	19.6	0.9	14.8	0	4	35	13.5	1.4	13.9	4.5
	570	0.5	0.5	51.4	41.9	6.7	0.3	4	0	2.3	35	12	0	33	8.3
	619	0.15	0.9	62.3	10.3	27.4	1.5	20.2	0	6	55.7	3	1	9	0
	623	0.3	0.45	79.9	19.4	0.7	3.3	0.3	0	0.3	63.3	10	0	17.3	1.7
	852	0.06	0.55	60.8	12.8	26.4	4.5	14.3	6.8	3.8	48.1	2.3	3	9	0
	976	0.12	0.42	64.5	8.9	26.6	21.1	17.2	4	4	31.1	3.5	3	5.5	0
	1060	0.35	0.45	60.7	23.6	15.8	0.7	10.3	0	5.3	44.3	6.3	1	18	4
	1061	0.3	0.5	70.1	19.8	10	1.9	5.9	0	4.3	52.1	8.1	1.4	13.3	3.8
	1177	0.26	0.45	58.3	23.5	18.2	7.4	5.1	1.8	10.6	37.7	4.2	7.9	8.8	4.7
	1246	0.06	0.42	71.7	14.2	14.2	14.4	10.2	0.9	1.7	46.6	0.9	5.1	7.6	0
	1286	0.28	0.47	51.1	17.6	31.3	5.1	18	0	17.1	33.2	7.4	2.8	10.1	3.2
	1350	0.1	0.45	69.4	9.2	21.4	8.4	14.5	0	4.2	46.4	7.2	2.4	6	0
	1458	0.3	0.47	18.8	16.4	64.8	0.5	9.3	0	54.9	14.2	2.5	4.4	9.3	2
	1493	0.27	0.4	36.6	26.2	37.1	1.6	13.2	0	24.7	30.6	2.3	7.3	16.4	1.4
	1528	0.62	0.7	12.3	6.7	80.9	0	8.9	0	73.4	7.2	1.7	0.8	3.8	1.7
	1533	0.35	0.45	44.7	27.7	27.6	1.3	4	0	23.3	39.7	2.7	1.3	20.7	5.3
	1562	0.09	0.65	60.6	11	28.4	3.8	9.9	0	17.6	45.8	6.9	4.6	5.3	0.8
	1624	0.75	1	53.5	26.8	19.7	0.9	10.3	0	9.4	38.8	10.3	0.9	21.9	3.6
	1635	1.5	1	32.3	11	56.7	1.7	1.7	0	55	9.9	7.9	0.8	4.6	4.1
Mean D1		0.37	0.63	51.13	18.21	30.66	3.77	12.10	0.64	17.37	36.10	5.76	2.53	12.05	2.73
Laramie	1720	0.35	0.45	29.7	14.5	55.8	2.7	2.7	0	50.3	21.3	3.3	0	11.7	2
Fox Hills	1861	0.32	0.45	82.6	15.7	1.7	3.3	0	0	1.7	63.7	12	2	11.7	1.7
	1883	0.35	0.6	61.5	17	1.4	3.3	0.5	0	1	56.7	19.1	2.9	12.4	1.4
	1927	0.22	0.47	75.3	17.8	6.9	6.8	3.1	0	3.1	54.5	8.9	6.3	8.9	2.1
	1963	0.11	0.4	76.3	10.7	13.1	11.7	10.2	0	2.4	47.1	2.9	1.5	8.3	0.5
	2012	0.07	0.45	73.6	8.6	17.9	9.3	10.7	6	0	54	4	3.3	4.7	0
	2046	0.07	0.4	74.2	10	15.8	11.9	10.5	2.8	0	44.1	4.9	2.1	6.3	0
	2080	0.1	0.38	60.9	16	23.1	6.4	10.9	3	6.9	39.1	6.9	9.4	5.5	0.5
Mean FH		0.18	0.45	72.06	13.69	11.41	7.53	6.56	1.69	2.16	51.31	8.39	3.93	8.26	0.89
Pierre	2131	0.1	0.38	60.6	19.4	20	8.2	9.8	4.3	2.4	39.6	3.9	5.3	12.5	0.5
	2184	0.1	0.38	65.5	14.2	20.4	7.4	11.3	5	2.5	50.3	1.2	5	7.4	0.6
	2194	0.07	0.45	64.4	12.3	23.3	8	11.7	6	1.2	46.9	2.5	6.2	4.9	0
	2220	0.1	0.42	64.8	11.7	23.5	5.9	17.1	3.5	1.8	45.9	4.7	5.3	5.9	0
	2242	0.06	0.45	60.6	9.2	30.3	3.4	16.8	9.2	0.8	48.7	3.4	5	3.4	0
Mean, PS		0.09	0.42	63.18	13.36	23.50	6.58	13.34	6.00	1.74	46.28	3.14	5.36	6.82	0.22

Table 10. Data from fission-track analyses of zircons from the Kiowa #1 core

Depth (ft)	Formation	Zircon mount #	Etch time (hrs)	Total grains examined	Number of metamic grains	Number of t grains	Number of overetched grains	Number of underetched grains	Number of datable metamic	%	% t volcanic
236.5 - 237.2	D2	1/2	7	48	33	1	2	12		**69**	**2**
564.6- 565.1	D1	1/2	6	48	32	3	4	9		**68**	**1**
		3	16	29	20	2	6	1			
		4	27	29	20	3	1	5			
685.9- 686.6	D1	1	8	109	36	35	12	26		**48**	**2**
		2	not examined								
		3	30	91	59	9	0	23			
		4	2	25	13	6	4	2			
848.6- 848.9	D1	1/2	17	7	3	1	0	3		**43**	**28**
1062.5- 1063	D1	1/2	25	18	1	5	1	11		**5**	**17**
1199.7- 1200.2	D1	1/2	18	57	23	14	2	18		**34**	**17**
		3	24	74	20	21	11	22			
		4	30	45	17	8	0	20			
1394.4- 1395.2	D1	1/2	27	30	19	5	0	6		**46**	**2**
		3	4	70	21	15	21	13			
		4	16	64	35	11	4	14			
1633- 1633.3	Arapahoe	1/2	5	2	2	0	0	0		**26**	**4**
		3	30	22	5	4	3	10			
		4	18	25	6	2	12	5			
1715.5- 1715.8	Laramie	1/2	11	36	8	7	6	7		**22**	**0**
1864- 1864.5	Fox Hills				no zircon						
2076.4- 2076.6	Fox Hills- Pierre transition	1/2	9	71	30	14	10	17		**46**	**5**
		3	12	60	28	13	9	10			
		4	24	32	17	4	4	7			

Table 11. Temperature data for Kiowa #1 core hole measured using hand logging equipment
DMNH Kiowa #1 8S/63W-17 SE NW

	Log run 1	Log run 3	Log run 4
	4/6/1999	10/29/1999	4/14/2000
Depth (m)	**Temperature (°C)**	**Temperature (°C)**	**Temperature (°C)**
10	no data	no data	10.4
15	11.56	no data	no data
20	11.8	10.61	11.1
25	11.78	10.66	no data
30	11.88	10.73	10.7
35	11.94	10.82	no data
40	12.04	10.91	11
45	12.11	10.99	no data
50	12.29	11.12	11.1
55	12.39	11.24	no data
60	12.59	11.38	11.3
65	12.73	11.52	no data
70	12.86	11.62	11.6
75	12.91	11.76	no data
80	13.03	11.91	11.9
85	13.09	12.03	no data
90	13.2	12.14	12.1
95	13.29	12.27	no data
100	13.43	12.51	12.38
105	13.57	12.71	12.58
110	13.72	12.89	12.76
115	13.85	13.07	12.93
120	13.97	13.28	13.14
125	14.14	13.46	13.32
130	14.28	13.64	13.5
135	14.45	13.81	13.68
140	14.64	14.04	13.89
145	14.76	14.18	14.05
150	14.94	14.35	14.22
155	15.07	14.56	14.43
160	15.22	14.59	14.47
165	15.35	no data	no data
170	15.48	no data	no data
175	15.65	no data	no data
180	15.8	no data	no data
185	15.97	no data	no data
190	16.14	no data	no data
195	16.28	no data	no data
200	16.45	no data	no data
205	16.59	no data	no data
210	16.75	no data	no data
215	16.88	no data	no data
220	17.05	no data	no data
225	17.29	470	25.13
230	17.51	475	25.33
235	17.69	480	25.5
240	17.87	485	25.65
245	18.05	490	25.82
250	18.24	495	25.97
255	18.43	500	26.12
260	18.62	505	26.27
265	18.82	510	26.46
270	18.98	515	26.66
275	19.13	520	26.86
280	19.31	525	27.02

Table 12. Temperature data for Kiowa #1 core hole measured using truck-mounted logging equipment

Log run 2 7/6/1999

Depth (m)	Temp. (°C)	Depth (m)	Temp (°C)	Depth (m)	Temp (°C)	Depth (m)	Temp (°C)
2	27.9206	6.5	14.0105	11	12.4879	15.5	11.7894
2.1	17.8877	6.6	13.9579	11.1	12.4684	15.6	11.7764
2.2	17.7999	6.7	13.9072	11.2	12.4518	15.7	11.7769
2.3	17.7125	6.8	13.8621	11.3	12.4333	15.8	11.7669
2.4	17.6069	6.9	13.8074	11.4	12.4138	15.9	11.7598
2.5	17.5232	7	13.7607	11.5	12.3906	16	11.7493
2.6	17.4278	7.1	13.7111	11.6	12.368	16.1	11.7372
2.7	17.3252	7.2	13.6547	11.7	12.3535	16.2	11.7257
2.8	17.2304	7.3	13.6022	11.8	12.3314	16.3	11.7152
2.9	17.1377	7.4	13.5571	11.9	12.3183	16.4	11.7046
3	17.0369	7.5	13.5194	12	12.3018	16.5	11.6911
3.1	16.9296	7.6	13.4803	12.1	12.2822	16.6	11.6846
3.2	16.8233	7.7	13.4432	12.2	12.2647	16.7	11.673
3.3	16.7296	7.8	13.4056	12.3	12.2511	16.8	11.665
3.4	16.6243	7.9	13.3654	12.4	12.2279	16.9	11.6549
3.5	16.5185	8	13.319	12.5	12.2115	17	11.6461
3.6	16.4142	8.1	13.2781	12.6	12.1899	17.1	11.6319
3.7	16.3079	8.2	13.2405	12.7	12.1753	17.2	11.6248
3.8	16.2031	8.3	13.2084	12.8	12.1623	17.3	11.6178
3.9	16.0963	8.4	13.1748	12.9	12.1492	17.4	11.6113
4	15.9761	8.5	13.1422	13	12.1357	17.5	11.6058
4.1	15.8601	8.6	13.1106	13.1	12.1211	17.6	11.5962
4.2	15.7543	8.7	13.078	13.2	12.1036	17.7	11.5867
4.3	15.6621	8.8	13.0494	13.3	12.0887	17.8	11.5731
4.4	15.5688	8.9	13.0102	13.4	12.0695	17.9	11.5671
4.5	15.4785	9	12.9751	13.5	12.0534	18	11.5577
4.6	15.3807	9.1	12.9475	13.6	12.0414	18.1	11.549
4.7	15.2875	9.2	12.9179	13.7	12.0248	18.2	11.537
4.8	15.2067	9.3	12.8903	13.8	12.0097	18.3	11.5365
4.9	15.1225	9.4	12.8693	13.9	11.9927	18.4	11.5295
5	15.0407	9.5	12.8432	14	11.9766	18.5	11.524
5.1	14.9675	9.6	12.8116	14.1	11.9656	18.6	11.5149
5.2	14.8893	9.7	12.784	14.2	11.9485	18.7	11.5039
5.3	14.8191	9.8	12.7599	14.3	11.9338	18.8	11.4969
5.4	14.7308	9.9	12.7358	14.4	11.9199	18.9	11.4893
5.5	14.6385	10	12.7122	14.5	11.9049	19	11.4838
5.6	14.5748	10.1	12.6826	14.6	11.8978	19.1	11.4768
5.7	14.5016	10.2	12.6651	14.7	11.8843	19.2	11.4718
5.8	14.4379	10.3	12.642	14.8	11.8722	19.3	11.4637
5.9	14.3747	10.4	12.6166	14.9	11.8552	19.4	11.4597
6	14.318	10.5	12.5928	15	11.8388	19.5	11.4477
6.1	14.2603	10.6	12.5687	15.1	11.8261	19.6	11.4437
6.2	14.2001	10.7	12.5466	15.2	11.8105	19.7	11.4361
6.3	14.1475	10.8	12.5326	15.3	11.8055	19.8	11.4276
6.4	14.0778	10.9	12.5105	15.4	11.797	19.9	11.4256
20	11.4206	24.9	11.1561	29.8	10.9523	34.7	10.7851
20.1	11.4155	25	11.1546	29.9	10.9511	34.8	10.7856
20.2	11.4062	25.1	11.1465	30	10.9432	34.9	10.7801
20.3	11.3985	25.2	11.1449	30.1	10.9412	35	10.7791
20.4	11.3945	25.3	11.142	30.2	10.9397	35.1	10.7751
20.5	11.3879	25.4	11.1355	30.3	10.9382	35.2	10.7701
20.6	11.3794	25.5	11.1305	30.4	10.9317	35.3	10.7651
20.7	11.3769	25.6	11.128	30.5	10.9317	35.4	10.7595
20.8	11.3759	25.7	11.1219	30.6	10.9262	35.5	10.758
20.9	11.367	25.8	11.1159	30.7	10.9212	35.6	10.755
21	11.3623	25.9	11.1114	30.8	10.9171	35.7	10.75

Table 13. $^{40}Ar/^{39}Ar$ analytical data for TF9912A and 92-O-33, tuffs from the Denver Basin. Numbers in bold represent the unweighted mean age and the error of the mean at the 95% confidence level, including error in J. These ages were used to constrain the interpretation of the paleomagnetic data.

Sample	Lab. No.	J	No. grains	$^{40}Ar/^{39}Ar$	$^{38}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	K/Ca	% Rad	$^{39}Ar^{*}/^{39}Ar$	Age (Ma) ± 1 sigma
TF9912A	00Z0169	0.006994	1	5.26009	0.013232	0.02301	0.000182	21.3	98.85	5.19943	64.44 ± 0.44
JD031	00Z0170		1	5.28249	0.013204	0.023546	0.000392	20.81	97.67	5.15974	63.95 ± 0.47
	00Z0171		1	5.23984	0.013099	0.017221	0.000248	28.45	98.46	5.15923	63.95 ± 0.32
	00Z0172		1	5.22492	0.013059	0.022199	0.000147	22.07	99.03	5.1743	64.13 ± 0.31
	00Z0173		1	5.19693	0.013063	0.022105	0.000113	22.17	99.22	5.15658	63.92 ± 0.31
	00Z0174		1	5.22114	0.013236	0.020839	0.000143	23.51	99.05	5.17162	64.10 ± 0.31
	00Z0175		1	5.20714	0.013421	0.020063	0.000001	24.42	99.86	5.19974	64.44 ± 0.41
											64.13 ± 0.21
92-O-33	93Z0740	0.007691	8	4.78809	0.013631	0.014751	0.000019	33.22	99.71	4.77446	65.06 ± 0.22
JDO13	93Z0741		8	4.78268	0.013459	0.015008	0.000043	32.65	99.57	4.76218	64.89 ± 0.21
	93Z0742		8	4.80419	0.017506	0.02111	0.000064	23.21	99.45	4.778	65.10 ± 0.24
	93Z0743		7	4.79212	0.013613	0.015325	0.000023	31.97	99.7	4.77761	65.10 ± 0.23
	93Z0745		11	4.78448	0.013807	0.01919	0.000021	25.5	99.71	4.77086	65.01 ± 0.21
											65.03 ± 0.26

Reactor Corrections
$(^{40}Ar/^{39}Ar)_K = 0.0086$
$(^{36}Ar/^{37}Ar)_{Ca} = 0.000266$
$(^{39}Ar/^{37}Ar)_{Ca} = 0.00068$

Decay constants for ^{40}K
$0.581 \times 10^{-10}\ yr^{-1}$
$4.962 \times 10^{-10}\ yr^{-1}$
$K/K = 1.167 \times 10^{-4}$ atom/atom

COLOG

COLOG Division of Layne GeoSciences, Inc.

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PHONE (303) 279-0171 FAX (303) 278-0135

ELECTRIC, GAMMA

COM: DMNH
WELL: DMNH-1
FLD: KIOWA
ST: CO COUNTY: ELBERT

COMPANY: DENVER MUSEUM OF NATURAL HISTORY

WELL: DMNH-1

FIELD: KIOWA

STATE: CO COUNTY: ELBERT

LOCATION:

NW SE SEC 17 TWP 8 S RGE 63 W

OTHER SERVICES:

RWS

CALIPER

COMP. DENSITY

PERMANENT DATUM: GROUND LEVEL ELEVATION: NA

LOG MEAS. FROM: GROUND LEVEL 0 FEET ABOVE PERM. DATUM

DRILL MEAS. FROM: GROUND LEVEL

DATE ACQUIRED	3-24,31,4-6-99	3-24,31,4-6-99	3-24,31,4-6-99	3-24,31,4-6-99
RUN NUMBER	2	1	1	2
LOG TYPE	GAMMA RAY	16-64" NORMAL	SP & SPR	GUARD RESIST.
DEPTH-DRILLER	2256'	2256'	2256'	2256'
DEPTH-LOGGER	2244'	2244'	2244'	2244'
BTM LOGGED INTERVAL	2231'	2237'	2238'	1787'
TOP LOGGED INTERVAL	0'	80'	80'	178'
RECORDED BY	PAUL KOS	PAUL KOS	PAUL KOS	PAUL KOS
WITNESSED BY	BOB RAYNOLDS	BOB RAYNOLDS	BOB RAYNOLDS	BOB RAYNOLDS
FLUID LEVEL	26'	26'	26'	26'
FLUID TYPE	MUD	MUD	MUD	MUD
Rm at TEMP	NA	NA	NA	NA
TIME SINCE CIRC.	1/2 hr.	1/2 hr.	1/2 hr.	1/2 hr.
PROBE TYPE, S/N	RABPF 2020	EPF 1387	EPF 1387	IPF 1748
MODULE TYPE, S/N	UM 1483	UM 1483	UM 1483	UM 1483
LOGGING SPEED	12	12	12	12
A.S.D.E.	0.7'	0.8'	0.8	0.7
SAMPLE INTERVAL	0.2	0.2	0.2	0.2
SOURCE SIZE, S/N	NONE	NONE	NONE	NONE

Plate 1 Electric and gamma logs from the Kiowa #1 well (page 1 of 6)

BOREHOLE RECORD			CASING RECORD		
BIT SIZE	FROM	TO	SIZE/WGT	FROM	TO
8"	SURF	82'	6"	SURF	82'
5 7/8"	82'	1797'	4"	SURF	1797'
3 8"	1797'	TD			

COMMENTS:

WELL WAS DRILLED AND LOGGED IN THREE STAGES
STAGE 1 - SURF TO 562' ON 3-24-99
STAGE 2 - 550' TO 1797' ON 3-31-99
STAGE 3 - 1797' TO 2256' ON 4-6-99

NA NOT AVAILABLE

COMMENTS:

STAGE 1 WAS DRILLED TO 1882', BUT THE WELL COLLAPSED AT 562'.

1800 TO 1860 FEET LOGGED THROUGH DRILL RODS DUE TO UNSTABLE BOREHOLE CONDITIONS.

DIGITAL FILES: DMNH-1.DAT, DMNH-1R.DAT

WELL: DMNH-1 3-23-99, 3-30-99, 4-5-99 COLOG

SPONTANEOUS POTENTIAL			64" NORMAL RESISTIVITY			GUARD RESISTIVITY		
100	MILLIVOLTS	-100	0	OHM-M	50	0	OHM-M	5
NATURAL GAMMA			16" NORMAL RESISTIVITY			SINGLE POINT RESISTANCE		
0	CPS	200	0	OHM-M	50	0	OHMS	20

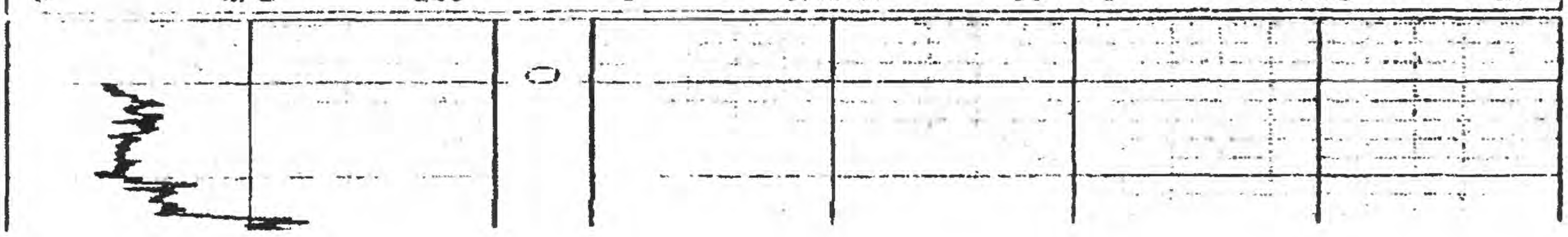

Plate 1 Electric and gamma logs from the Kiowa #1 well (page 2 of 6)

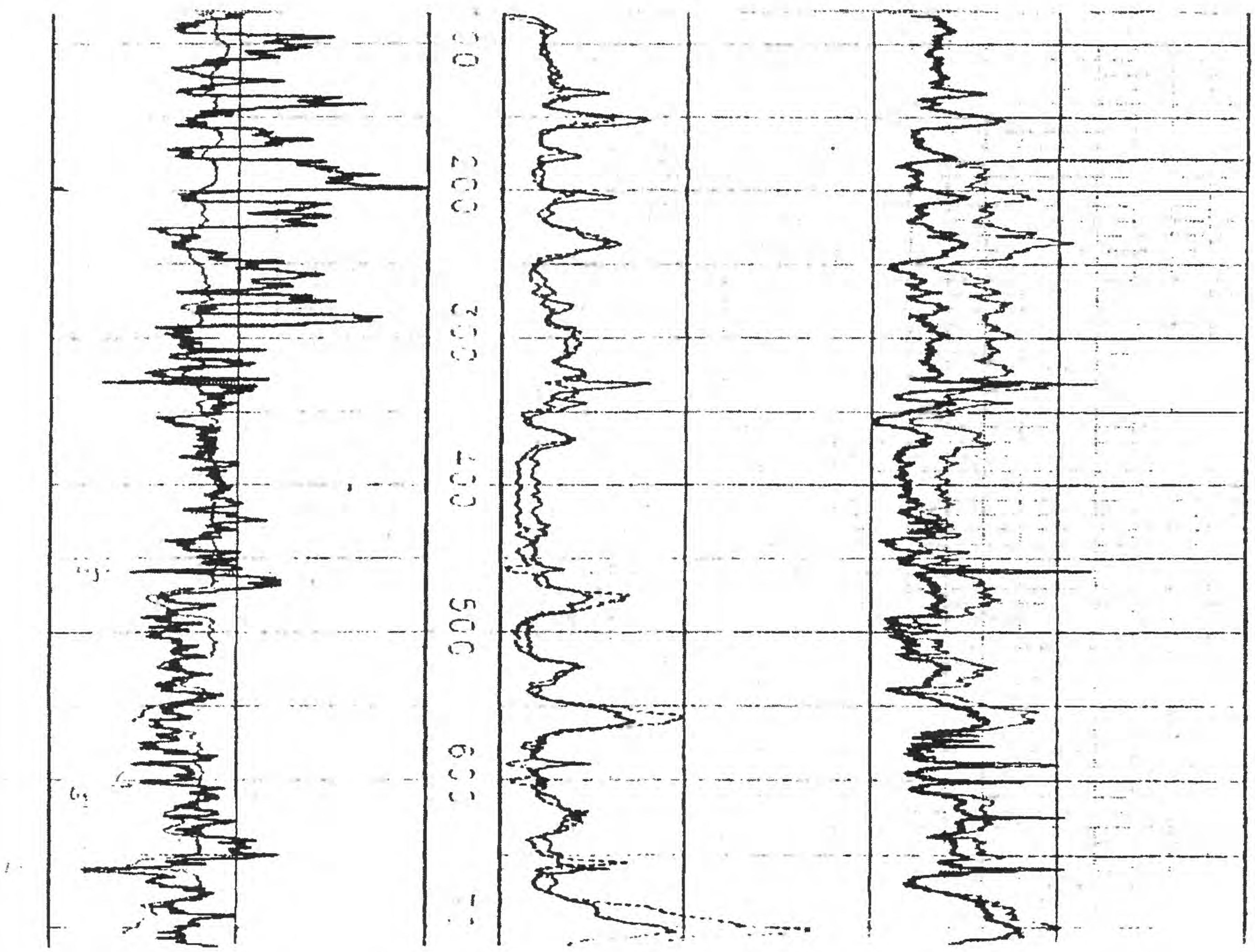

Plate 1 Electric and gamma logs from the Kiowa #1 well (page 3 of 6)

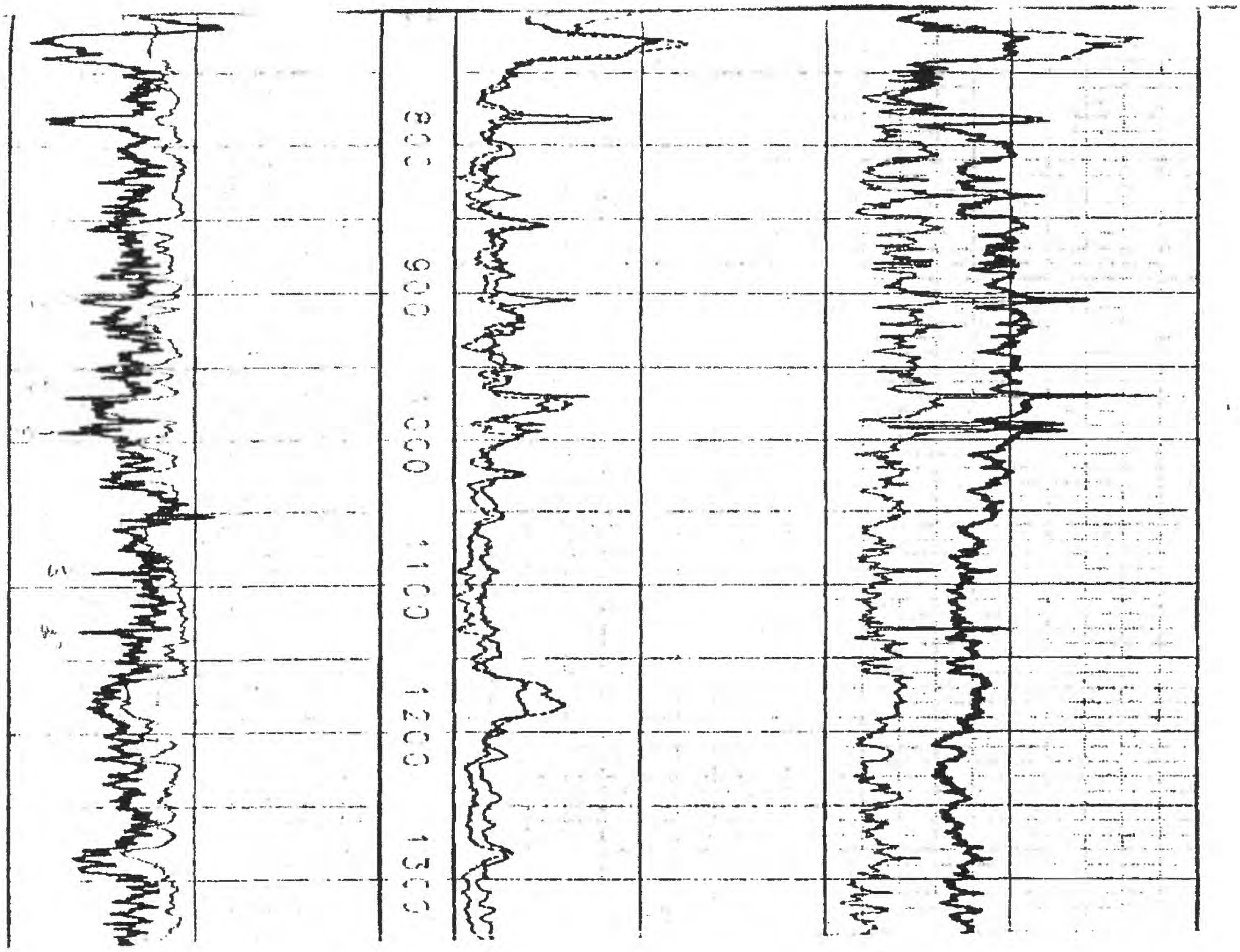

Plate 1 Electric and gamma logs from the Kiowa #1 well (page 4 of 6)

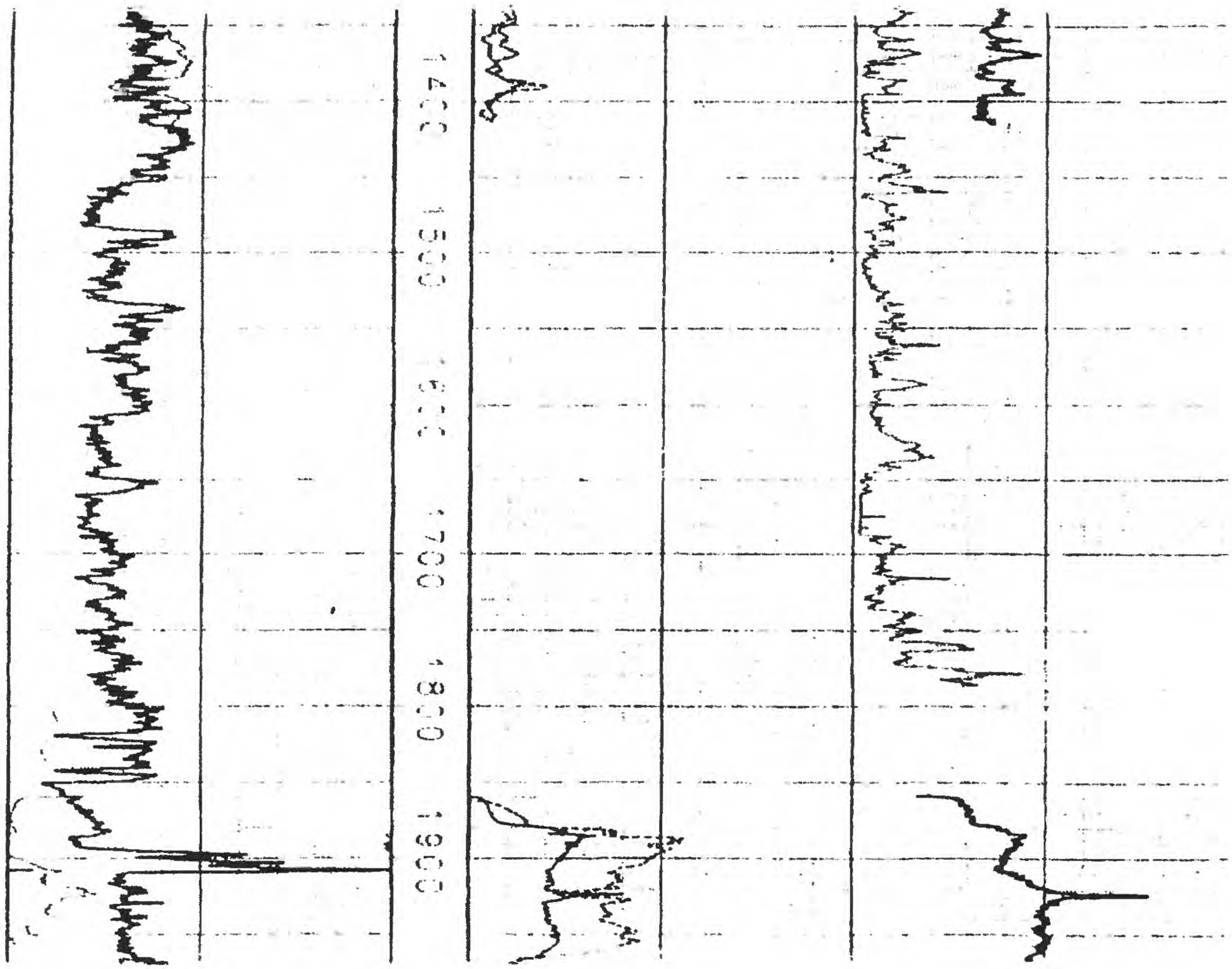

Plate 1 Electric and gamma logs from the Kiowa #1 well (page 5 of 6)

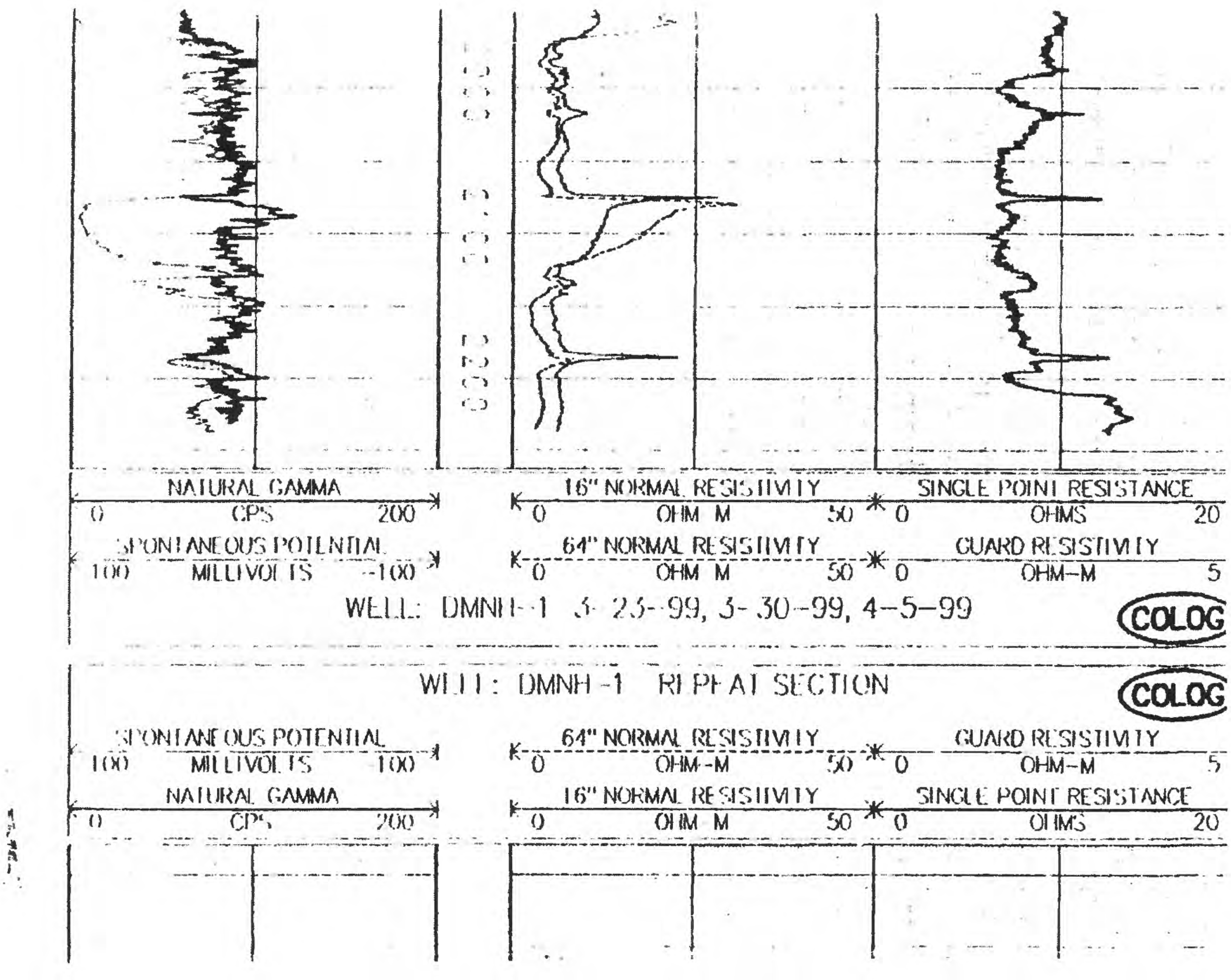

Plate 1 Electric and gamma logs from the Kiowa #1 well (page 6 of 6)

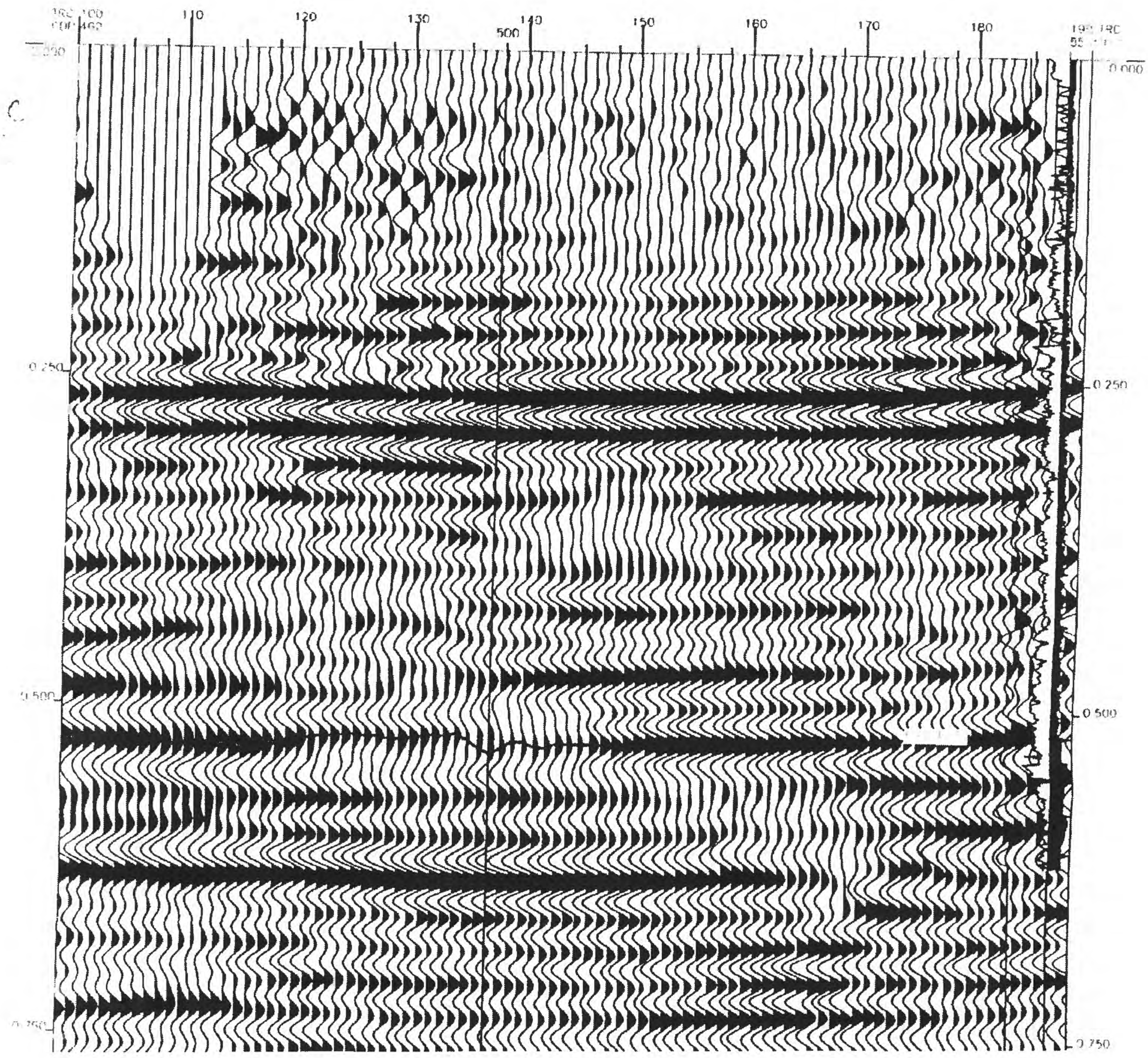

Plate 2 Seismic line running adjacent to the Kiowa #1 core hole. Reflectors at 0.25 ms represent lignites. Line length approximately 1.5 miles.